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INFLUENCE OF DOWNFLOODING ON IROQUOIS CLASS DAMAGE STABILITY

K. McTaggart

DEFENCE RESEARCH ESTABLISHMENT ATLANTIC

Technical Memorandum

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March 2000

TECHNICAL MEMORANDUM

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Canada

Abstract

This report examines stability in waves of a damaged Iroquois class ship. Stern asymmetric flooding is the limiting design case for the Iroquois class. To reduce heel angle for this limiting case, DND is considering installing ports to permit downflooding to lower compartments, resulting in a lower centre of gravity for the damaged ship. The computer program FREDYN has been used to examine motions in waves for the damaged ship with and without downflooding. In calm water and moderate sea states, the maximum roll angle occurs during transient motions immediately after damage. These transient motions are not included in current stability criteria. Downflooding significantly reduces the static list of the damaged ship in calm water; however, the initial roll transient that occurs immediately after damage is not significantly influenced by downflooding. For the damaged ship in higher sea states, FREDYN simulations indicate that allowing downflooding gives somewhat reduced roll motions. The FREDYN program appears promising for assessing performance of damaged ships in waves. Further development efforts should be directed toward program validation, robustness, and visualization capabilities.

Résumé

Le présent rapport examine la stabilité dans les vagues d'un navire endommagé de la classe Iroquois. L'envahissement asymétrique par l'arrière est le cas de calcul aux états limites pour les navires de cette classe. Pour réduire l'angle d'inclinaison du cas limite, le MDN envisage d'installer des hublots qui permettraient de noyer les compartiments inférieurs des navires endommagés et d'abaisser ainsi leur centre de gravité. L'examen des mouvements dans les vagues d'un navire endommagé avec ou sans envahissement par les hauts s'est fait à l'aide du programme informatique FREDYN. En eaux calmes et par état de mer modéré, l'angle d'inclinaison latéral maximal survient pendant les mouvements transitoires immédiatement après l'endommagement. Ces mouvements transitoires ne font pas partie des critères de stabilité actuels. L'envahissement par les hauts réduit de façon significative la gte statique des navires endommagés en eaux calmes mais il n'a pas d'incidence marquante sur l'état de roulis transitoire initial qui survient immédiatement après l'endommagement. En ce qui concerne les navires endommagés dans des mers plus mauvaises, la simulation faite avec le programme FREDYN indique qu'un certain niveau d'envahissement permet de réduire les mouvements de roulis. L'évaluation du rendement des navires endommagés dans les vagues à l'aide du programme FREDYN semble prometteuse. Les prochains efforts de développement devraient porter sur la validation, la robustesse et les capacités de visualisation du programme.

DREA TM 2000-038

INFLUENCE OF DOWNFLOODING ON IROQUOIS CLASS DAMAGE STABILITY

by

Kevin A. McTaggart

EXECUTIVE SUMMARY

Introduction

For naval ships, the allowable height of the centre of gravity is determined by static stability criteria. A ship must maintain stability for both intact and damaged design scenarios. For the Iroquois class (and for many other naval vessels), stern asymmetric flooding induced by damage is the limiting design case. To reduce list for this limiting case, DND is considering installing ports to permit downflooding to lower compartments, resulting in a lower centre of gravity for the damaged ship. The computer program FREDYN has been used to examine motions in waves for the damaged ship with and without downflooding.

Principal Results

For the present damaged ship simulations, the maximum roll angle usually occurs during the initial roll transient immediately after damage. Downflooding significantly reduces the list of the damaged ship in calm water; however, the initial roll transient is not significantly influenced by downflooding. For the damage ship in higher sea states, FREDYN simulations indicate that allowing downflooding gives somewhat reduced roll motions. FREDYN predictions were sensitive to the input time step size, and appeared to converge for a time step of 0.1 s.

Significance of Results

The transient roll motion which occurs immediately after damage is approximately 30 percent larger than the static list in calm water, and should be considered when evaluating damage stability. When predicting damaged ship motions with FREDYN, the sensitivity of results to input time step size indicates that the program should ensure that the time step is sufficiently small for simulated conditions. Despite its current limitations, FREDYN appears to be a very promising tool for evaluating motions of damaged ships in waves.

Future Plans

Ongoing development of FREDYN will address the areas of validation, robustness, and visualization for motions of damaged ships in waves. The improved program will be used to develop new design and operational stability guidelines for damaged ships in waves.

DREA TM 2000-038

INFLUENCE DE L'ENVAHISSEMENT PAR LE HAUT SUR LA STABILITÉ APRÈS AVARIE POUR LA CLASSE IROQUOIS

par

Kevin A. McTaggart

SOMMAIRE

Introduction

La hauteur permise du centre de gravité des navires de guerre est déterminée par des critères de stabilité statique. Pour les scénarios de conception, un navire doit maintenir sa stabilité à l'état intact ou en avarie. Pour la classe Iroquois (et de nombreux autres navires de guerre), l'envahissement asymétrique par l'arrière à la suite de dommages est la limite de conception. Pour réduire la gîte de ce cas limite, le MDN envisage de percer des ouvertures pour permettre l'envahissement de compartiments inférieurs, abaissant le centre de gravité du navire endommagé. On a utilisé le programme informatique FREDYN pour examiner les mouvements dans les vagues, avec et sans envahissement par le haut.

Principaux résultats

Dans les simulations de navire en avarie, l'angle de roulis maximal se produit pendant le transitoire de roulis initial immédiatement après l'avarie. L'envahissement par le haut réduit de façon significative la gîte du navire en avarie par mer calme. Toutefois, le transitoire de roulis initial n'est pas influencé de façon significative par l'envahissement par le haut. Pour les navires en avarie dans des mers plus agitées, les simulations FREDYN indiquent que l'envahissement par le haut réduit le roulis dans une certaine mesure. Les prédictions FREDYN étaient sensibles à l'intervalle de temps introduit et semblaient converger pour un intervalle de 0,1 s.

Importance des résultats

Le mouvement de roulis transitoire qui suit immédiatement l'avarie est environ 30 pour cent plus important que la gîte statique par mer calme, et doit tre pris en compte dans l'évaluation de la stabilité du navire. Lorsqu'on prédit les mouvements du navire endommagé au moyen de FREDYN, la sensibilité des résultats à l'intervalle introduit indique que le programme devrait assurer que l'intervalle de temps est suffisamment petit pour des conditions simulées. Malgré ses limitations actuelles, FREDYN semble tre un outil très prometteur pour évaluer les mouvements de navires en avarie dans les vagues.

Plans futurs

Le développement en cours de FREDYN portera sur la validation, la robustesse et la visualisation des mouvements des navires en avarie dans les vagues. Le programme amélioré servira à développer de nouvelles lignes directrices de conception et de stabilité dans les vagues.

Contents

Notation

DTRTD	FREDYN input time step size
f_{in}	initial fraction of tank full
GM_{fluid}	corrected metacentric height (intact ship)
H	wave height
$\overline{KG}$	height of center of gravity above baseline
k	constant for checking time step size
L	length between perpendiculars
p_{dry}	dry tank permeability
p_{eff}	effective tank permeability
Q	inflow rate
SG	specific gravity
T	wave period
T_{AP}	draft at aft perpendicular
T_{FP}	draft at fore perpendicular
t	time
x, y, z	ship-based coordinate system
x_e, y_e, z_e	earth-based coordinate system
ϕ	roll angle
ϕ_{max}	maximum absolute roll angle
ψ	yaw angle
ψ_0	initial yaw angle
$\triangle$	ship mass displacement

1 Introduction

Stability standards for Canadian Forces ships are intended to give adequate stability against capsize for both intact and damaged ships. To pass these standards, limitations are placed on the maximum allowable height of centre gravity (i.e., $\overline{KG}$ value), thus restricting the placement of equipment on board the ship. In practice, the limiting $\overline{KG}$ values for Canadian naval ships are usually determined by damage stability requirements.

The main deficiency of current stability standards (e.g., Reference 1) is that they do not adequately consider the physics of ship capsize. Since 1990, the Cooperative Research Navies Dynamic Stability Project has been working toward more rational procedures for assessing ship stability in waves. The project has developed the FREDYN code [2, 3], for simulating motions in waves of intact and damaged frigates.

This report describes the application of FREDYN to predicting damage stability in waves of the Iroquois class. The study considers aft asymmetric flooding, which is the limiting damage case for Iroquois class vessels. The study also examines the influence of downflooding ports on damage stability behaviour. These ports could be installed to permit downflooding into two lower compartments on the damaged ship, resulting in a lower centre of gravity and improved damage stability.

The next section gives a description of the FREDYN damage suite and its implementation at DREA. Section 3 describes the modelling of the Iroquois ship compartments for damage stability computations. Simulations of motions in waves are presented in Section 4, followed by discussion of results in Section 5. Recommended improvements to the FREDYN damage suite are given in Section 6. Section 7 gives concluding remarks. The appendices give sample input and output files.

2 FREDYN Damage Suite

The FREDYN damage suite, described in References 2 and 3, includes the following programs listed in the order of typical usage:

- CDAWSP computes hull section properties,
- OUT2SHCP prepares input files for SHCP,
- SHCP computes volume properties of ship compartments,
- COMPCOEF converts SHCP output to a format used by FREDYN,
- FREINP computes ship hydrodynamic coefficients,
- FREDYN computes ship motions in waves using time domain simulation.

With the exception of SHCP, the above programs have been developed by Maritime Research Institute Netherlands (MARIN).

The program SHCP (Ship Hull Characteristics Program) [4] was developed by the US Navy for comprehensive analysis of intact and damage stability properties. The extensive capabilities of SHCP make it a difficult program to fully understand and use. As an alternative to fully

learning about SHCP input requirements, the FREDYN user can use the simpler program OUT2SHCP to prepare required input for SHCP.

Version 7.9 of the FREDYN suite was used for the present study. To allow debugging of run time errors, the programs from the FREDYN suite (with the exception of SHCP) were compiled at DREA using the Digital Visual Fortran 6 compiler. For successful compilation using the Digital Visual Fortran 6 compiler, the code required some minor modifications to conditional compiler directive statements.

3 Modelling of Damaged Ship

This study considers damage stability for the Iroquois class, with particulars as given in Table 1. The limiting damage case, which is called 05AS Operational Light, consists of stern asymmetric flooding and is shown in Figure 1 with the damage opening. Figures 2 and 3 illustrate the compartments free to flood for this case. In Figure 3, inboard compartments 6009, 6016, and 6054 are hidden even though they are free to flood. Compartment numbers are based on FREDYN input files prepared by MARIN, as described in Reference 5. The first digit of each compartment number indicates the deck number for the compartment. For compartments on deck 6, most of them also extend vertically through deck 5. On Figure 2, compartments 5012, 6026, and 6053 are marked with asterisks because they are not free to flood for damage case 05AS Operational Light. This study examines the influence on damage stability of installing ports to permit downflooding into compartments 5012 and 6053. The locations of the proposed downflooding ports are shown on the drawings for decks 4 and 6 in Figure 2. It should be noted that the ports would be installed on deck 4. Compartment 6026 is beneath compartment 5012, and is not subject to any flooding. Figure 3 gives a starboard profile of the damaged portion of the ship with the opening for damage case 05AS. The damage opening is an ellipse measuring 18.29 m long by 5.49 m high. The centre of the ellipse is located 28.65 m forward of the aft perpendicular, and its base is 1.52 m above the baseline. The solid ellipse in Figure 3 is the actual size of damage to be modelled, while the dashed line is a representation for FREDYN input based on four quadrilaterals that each have a point at the center of the ellipse.

Table 1: Main Particulars for Iroquois Class, Operational Light Condition

Length, L	121.31 m
Beam, B	15.22 m
Draft at fore perpendicular, T_{FP}	5.019 m
Draft at aft perpendicular, T_{AP}	5.059 m
Displacement, $\triangle$	5170 tonnes
Vertical centre of gravity, $\overline{KG}$	6.393 m
Corrected metacentric height, GM_{fluid}	0.991 m

Modelling of damage stability requires geometric descriptions of all compartments that will be flooded. A naval frigate can have over 100 compartments; thus, preparation of geometric

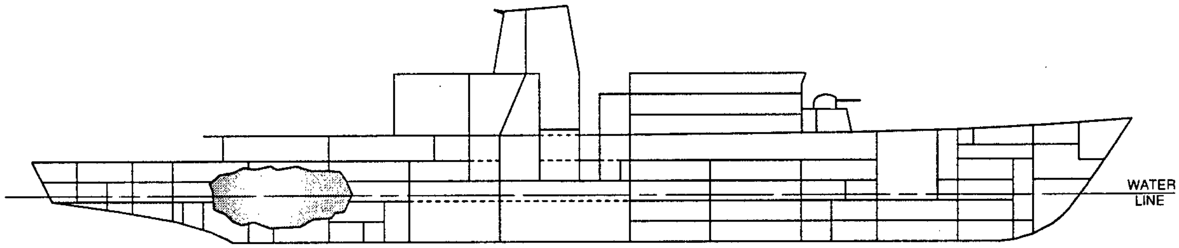

Figure 1: Starboard Profile of Iroquois Class Ship with Damage Opening

descriptions for compartments can be a large task. For the Iroquois class, DMSS already had compartment descriptions in GHS (General Hydrostatics Program) format. To facilitate damage stability computations using FREDYN, DMSS contracted MARIN to generate the required compartment descriptions, as described in Reference 5. MARIN produced initial SHCP input files using program OUT2SHCP. They subsequently modified the SHCP input files to get SHCP to run successfully. Comparisons between GHS and SHCP computed tank volumes gave excellent agreement, with volume differences for most tanks being less than one percent.

Although the SHCP files delivered by MARIN could be used to compute tank volumes with SHCP, they could not be used without modification for computing tank properties to be used as input for FREDYN. The first problem with the SHCP files provided by MARIN was that they modelled over 100 subdivisions, while FREDYN was only capable of handling 30 subdivisions. The second problem was that SHCP would crash due to numerical problems when computing tank properties for many different combinations of tank percentage full, heel angle, and trim angle. During a workshop held in September 1999, John Rosborough, the author of SHCP, provided useful guidelines regarding preparation of input to eliminate numerical problems. New SHCP files were made by modifying the files from MARIN as follows:

1. Offsets were provided for intermediate stations 10.5 to 17.5. (Station 0 is at the FP, station 20 at the AP). This step eliminated SHCP numerical errors when computing properties of many of the compartments.

2. Compartments not required for the downflooding study were eliminated from the SHCP input. This step reduced the number of compartments to a value within the limits of FREDYN.

3. All compartments free to flood for damage case 05AS Operational Light were modelled as one large subdivision. This step greatly reduced the potential for SHCP to crash because of numerical problems; however, it also introduced the assumption that all decks and bulkheads would be totally eliminated rather than being rendered non-watertight by damage.

4. The SHCP extreme input trim angles of ±30 degrees were replaced by values of ±10 degrees to eliminate numerical problems during SHCP computation of tank properties. A constant trim angle increment of 1 degree was used.

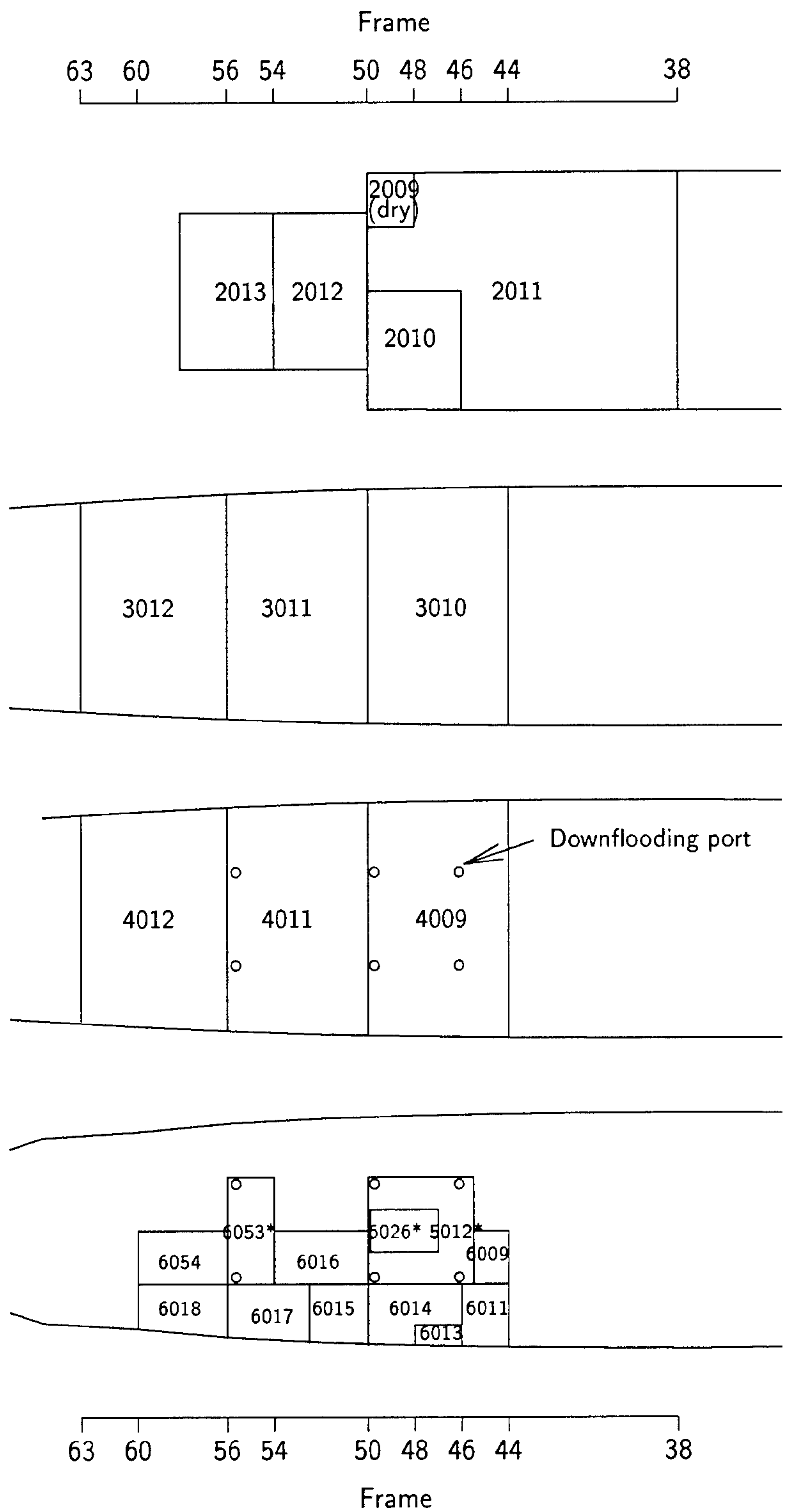

Figure 2: Compartments Free to Flood for Damage Case 05AS Operational Light

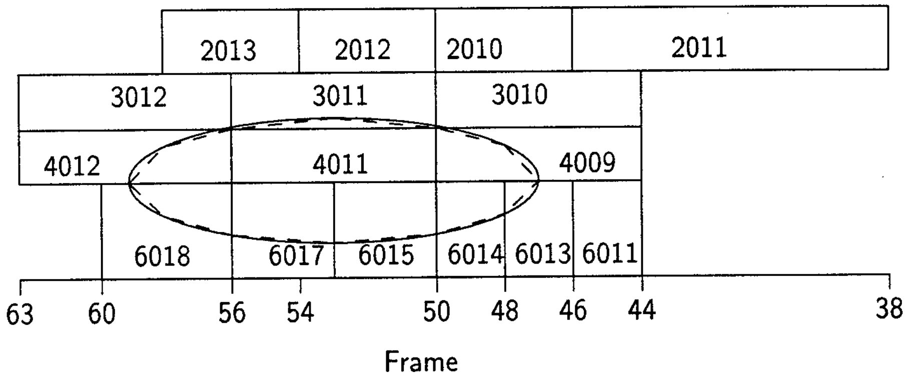

Figure 3: Starboard Profile of Damaged Portion of Ship

5. The increment between SHCP input roll angles was changed to a constant value of 10 degrees, with the exception of 9 degree increments between ±80 and ±89 degrees.

Figure 4 shows the ship sections used for computation of tank properties with SHCP. The dashed lines represent intermediate stations that were generated using girthwise interpolation.

As indicated above, the damaged portion of the ship was modelled as one large subdivision. This assumption likely resulted in a somewhat greater rate of inflow. In reality, the damaged internal subdivisions would impede the inflow and internal flow within the damaged ship.

When modelling the motions of the damaged ship, it was important for FREDYN to include the influence of fluids present in the intact ship before damage to affected compartments. The first attempt to model initial fluid used the FREDYN input record TANK to describe the fluids normally carried by the ship. The modelled initial fluid induced heel, sinkage, and trim on the ship. To counteract the induced heel, a counter tank having very dense fluid was introduced on the opposite side of the ship. To counteract the induced sinkage and trim, the FREINP intact fore and aft drafts were decreased such that a FREDYN simulation in calm water would give heave and pitch resulting in the actual intact fore and aft drafts. The dynamic roll properties of the modelled ship were then examined by performing roll decay simulations with and without initial fluid. Unfortunately, FREDYN gave very unrealistic results for the ship with initial fluid subjected to an initial roll angle of 4 degrees in calm water. For example, the ship acquired a sway velocity of 25 knots within the first 4 seconds of simulation. Consultations with MARIN indicated that the ability to model initial fluid will be addressed in future versions of FREDYN.

Given the current limitations of FREDYN for modelling initial fluid, it was decided that the best solution for modelling initial fluid would be to reduce permeabilities of tanks with initial fluids to model the remaining available space for fluid introduced by damage. The following equation was used for determining modified permeabilities:

$$p_{eff} = (1 - f_{in}) \times p_{dry} \tag{3.1}$$

where p_{eff} is effective permeability, f_{in} is fraction full of initial fluid, and p_{dry} is permeability for the dry tank. Using effective permeabilities gives the correct dynamic properties for the intact ship. The influence of initial fluids in intact compartments is included in the input weight distribution and metacentric height GM_{fluid} for the intact ship. For the damaged ship, errors are introduced by the following:

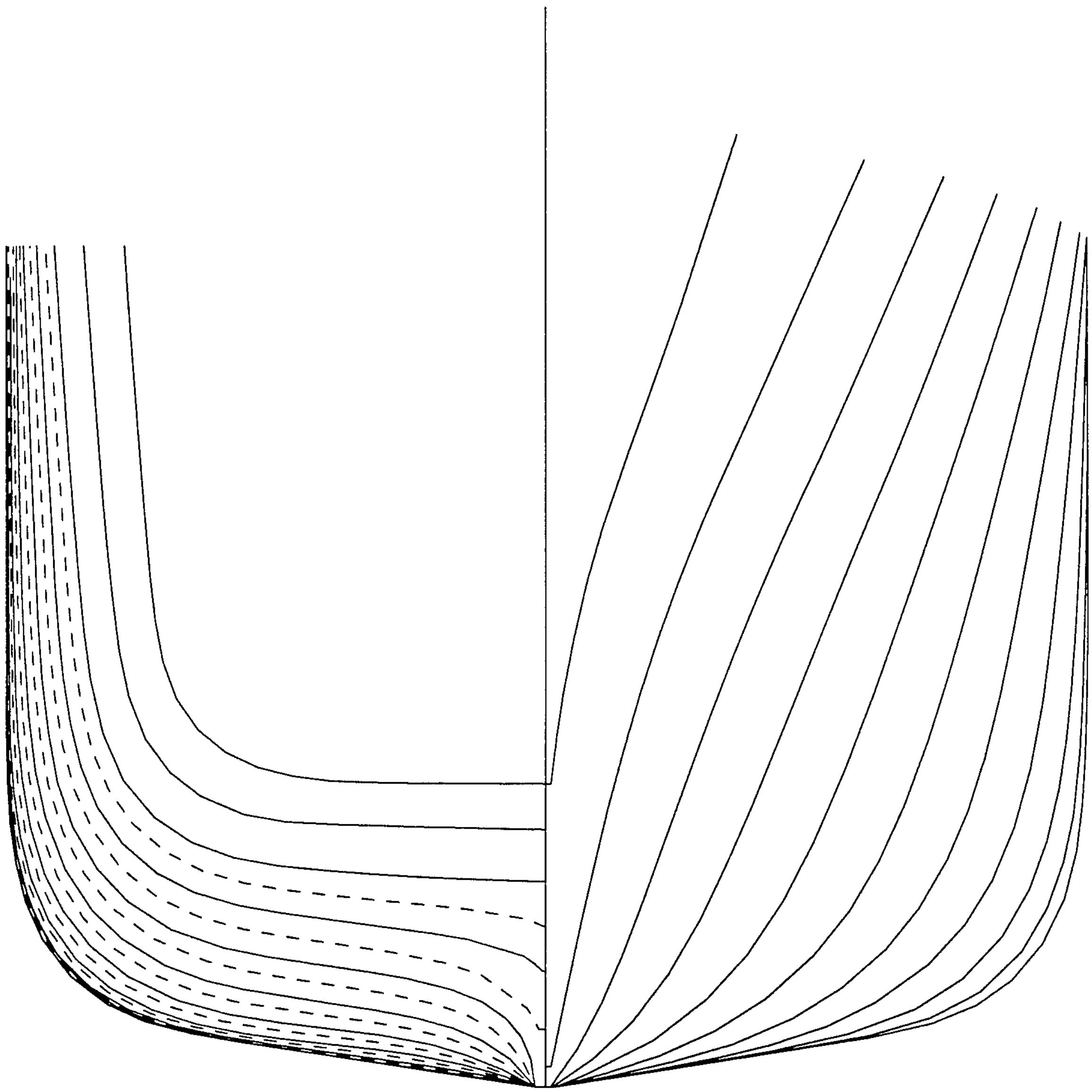

Figure 4: Iroquois Offsets for SHCP Computations

- the displacement of initial intact fluid by damage fluid of different density is not modelled,
- initial fluid is assumed to be evenly distributed within a compartment,
- motion of the initial fluid within compartments is not modelled.

Fortunately, the above errors are minimized by the following factors for Iroquois class ships:

- initial fluids have densities within 20 percent of the density of salt water,
- tanks with initial fluids are typically nearly full.

Table 2 gives tanks which have initial fluid for damage case 05AS Operational Light. Each tank has either fuel or salt water, with the exception of FREDYN tank 6016, which has both.

Table 2: Compartments with Initial Fluid for Damage Case 05AS Operational Light

GHS Label	FREDYN Number	*SG* Fluid	Percent Full $100f_{in}$	Dry Perm. p_{dry}	Effective Perm. p_{eff}
T6H-SERV1.S	6009	0.855	31.67	0.97	0.66
T6H-DFO5.S	6011	0.855	31.67	0.97	0.66
T6H-EXP7.S	6013	1.025	100	0.97	0.00
T6H-DFO7E.S	6014	1.025	100	0.97	0.00
T6J-DFO7D.S	6015	1.025	100	0.97	0.00
T6J-DFO7C.S	6016	0.855,1.025	8.7,91.3	0.97	0.00
T6J-DFO7B.S	6017	1.025	100	0.97	0.00
T6K-DFO7A.S	6018	1.025	100	0.97	0.00

To check the modelling of the damage case 05AS Operational Light using effective permeabilities in Table 2, FREDYN was run for the ship in calm water and the results were compared with damaged stability computations from the program GHS. Table 3 shows excellent agreement between GHS and FREDYN for the equilibrium damage condition.

Table 3: Comparison of GHS and FREDYN for Equilibrium Condition of Damage Case 05AS Operational Light

	GHS	FREDYN	Difference
Draft at fore perpendicular	4.481 m	4.524 m	0.9%
Draft at aft perpendicular	6.489 m	6.421 m	1.1%
Heel angle	19.82°	20.00°	0.9%

4 Simulations of Motions in Waves for Damaged Ship

After successful modelling of the static damage case 05AS Operational Light, simulations were performed to examine damage stability in waves at zero ship speed. To remove random effects caused by irregular waves, all simulations were performed in regular waves, with conditions as given in Table 4. The wave heights and corresponding periods are based on NATO sea states given in Reference 6.

Figure 5 shows the horizontal coordinate system used by FREDYN, where x_e, y_e are earth fixed axes and ψ is ship yaw angle relative to the x_e axis, the direction of wave propagation. Unless otherwise noted, the ship had an initial FREDYN heading of 90 degrees, meaning that the damage opening was to windward. The ship speed was zero for all simulations; thus, the ship steering system was ineffective. For each simulation, damage occurred after 20 s of simulation to allow the ship to approach an initial equilibrium condition for the intact case in waves. The 20 s delay was sufficiently short that the ship heading at the onset of damage was within ten degrees of the heading at the beginning of each simulation. A relatively long simulation duration of 1000 s was required to ensure that the damage equilibrium state was reached in each case.

Table 4: Wave Conditions for FREDYN Computations

Wave Height H	Wave Period T
0.88 m	7.5 s
1.88 m	8.8 s
3.25 m	9.7 s
5.00 m	12.4 s
7.50 m	15.0 s

Preliminary simulations for the damaged ship were found to have large initial transient motions at the onset of damage. The magnitude of these initial transients was found to be very sensitive to the time step size determined by input parameter DTRTD in FREDYN input record SIMPAR. FREDYN gave improved results when DTRTD was reduced from the default of 0.5 s to 0.1 s, as recommended for damaged ships in the FREDYN manual [3]. This reduced time step size were used for all simulations in this report unless otherwise noted.

To examine the effectiveness of downflooding, simulations were conducted with four ports allowing downflooding into compartment 5012 and two ports allowing downflooding into compartment 6053, with locations as shown in Figure 2. In most cases, each port had an area of 0.292 m^2. Some additional simulations had ports with smaller (0.164 m^2) and larger (0.456 m^2) areas. An inflow coefficient of 0.6 was assumed for all ports and damage openings. For simulations with downflooding ports, the ports opened simultaneously with the occurrence of damage. In reality, downflooding would likely be controlled by bursting disks, which would be manufactured to burst after being subjected to a prescribed level of flood water (e.g., 0.5 m). The presence of bursting disks would cause a delay between compartment damage and opening of the ports.

Figures 6 and 7 give maximum roll angles from simulations when the ship has an initial

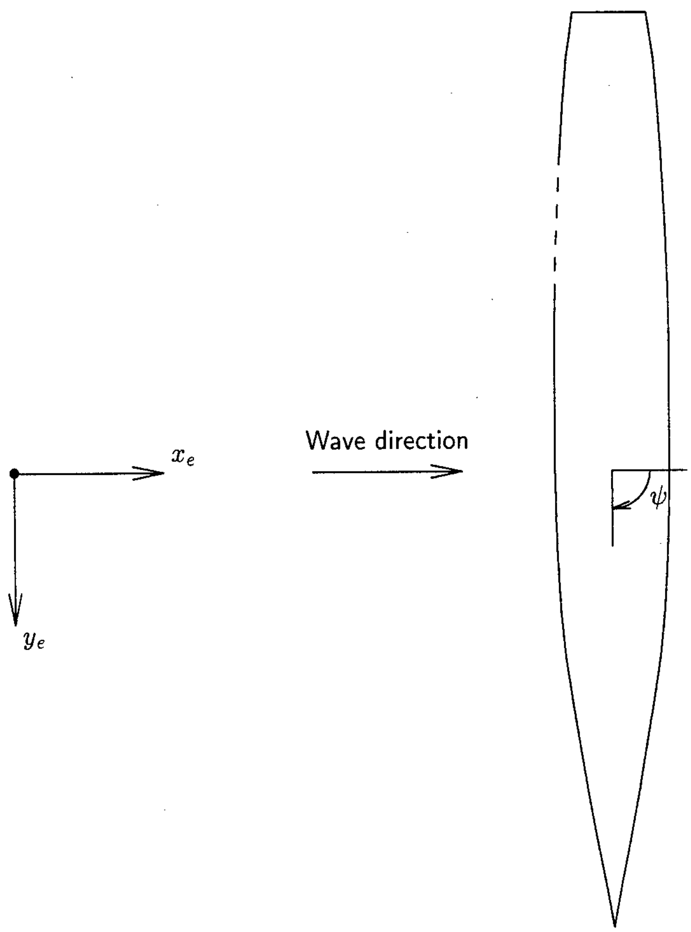

Figure 5: FREDYN Horizontal Coordinate System with Ship at 90 Degree Heading

heading of 90 degrees. Figure 6 includes the effect of initial transient motions, while Figure 7 excludes initial transient effects by neglecting the initial 300 s for each simulation. For wave heights of 3.25 m and below, the maximum roll angle occurs immediately after damage, and downflooding has little effect on the initial transient roll motions. Downflooding gives significant reductions to maximum roll angle after the initial transient motions.

Figure 8, which shows roll and yaw time series in calm water, provides insight into the response of the ship to damage. Downflooding ports have little effect on the initial transient response, but cause a significant reduction in the equilibrium list. The yaw time series show that the ship has very little yaw response when damage occurs in calm water.

Figure 9 shows the roll and yaw response of the ship for a wave height of 3.25 m and initial ship heading of 90 degrees. Results for a wave height of 3.25 m (NATO sea state 5) are shown because this condition occurs relatively often in the North Atlantic. For the case with no downflooding, the oscillatory roll motions show a surprising increase at approximately 200 s. It is uncertain whether this increase is due to physical phenomena or to problems with the FREDYN predictions. The simulations indicate that downflooding has little influence on the initial roll response to damage, but greatly reduces the list and oscillatory roll motions during the latter part of the simulations. For the case with no downflooding, the oscillatory roll motion amplitude appears to be decaying slowly at the end of the simulation, and the roll period is approximately twice the wave period.

To examine the influence of initial ship heading relative to the waves, Figure 10 shows roll and yaw responses for the damage case with no downflooding. After 900 s of simulation, the roll motions are very similar for initial headings of 180 and 270 degrees. For initial headings of 0 and 90 degrees, relatively large oscillatory roll motions occur with periods approximately twice that of the incident wave period. The large roll motions are slowing decaying at the end of the simulations. The large responses for initial headings of 0 and 90 degrees are likely related to the damage opening being on the windward side of the ship.

Figure 11 shows maximum roll angle for the different sizes of downflooding ports. The influence of port size is negligible for the range of port sizes considered.

To investigate the influence of damage hole size, additional simulations were run with a smaller damage opening, a rectangle 5 m long by 4 m high. A rectangular rather than elliptical opening was used for the smaller hole because it was easier to define than an ellipse and hole shape has little influence on inflow for smaller sized openings. For the smaller opening, the volume free to flood and hole center are the as for the larger design damage opening. Figure 12 shows maximum roll angle for the two different hole sizes and no downflooding. The influence of hole size on maximum roll angle is relatively small.

As mentioned previously, FREDYN motion predictions were found to be quite sensitive to the input parameter DTRTD, which is the time step for inflow rate calculations for a damaged ship. Most other terms influencing ship motions are determined at smaller variable-sized time steps based on numerical integration and the FREDYN input tolerance parameter TOL; thus, motion predictions for an intact ship are much less sensitive to the input time step size DTRTD. Figures 13 and 14 show roll predictions for different values of DTRTD with and without downflooding. The default time step size of 0.5 s gives very large initial transient motions. The smaller time step sizes of 0.1 and 0.2 s give similar results, although convergence has not yet been fully obtained. The present version of FREDYN does not permit input time steps smaller than 0.1 s.

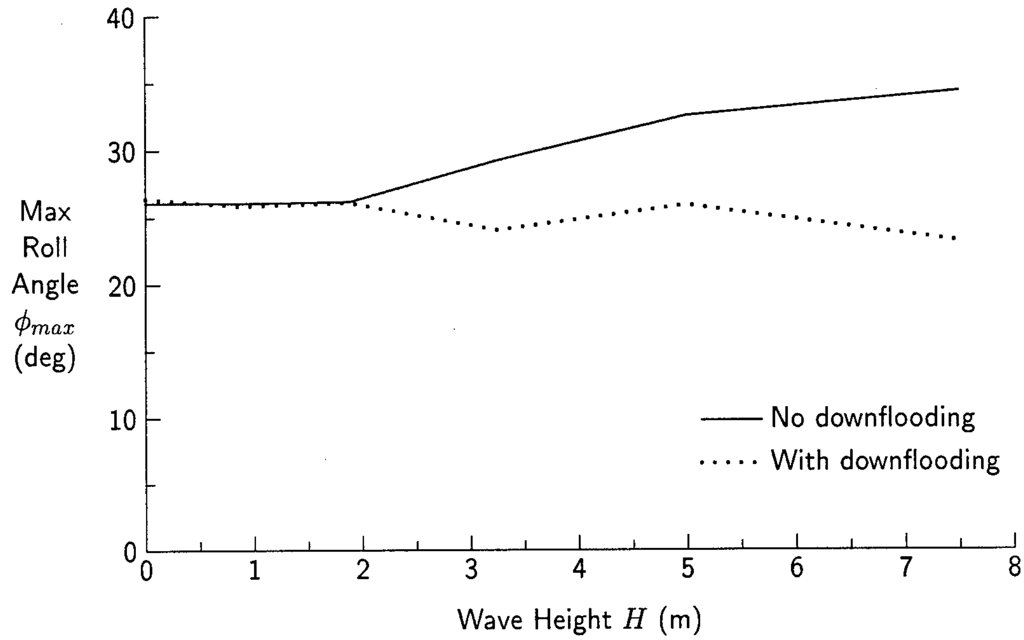

Figure 6: Maximum Absolute Roll Including Initial Transients, Initial Beam Seas

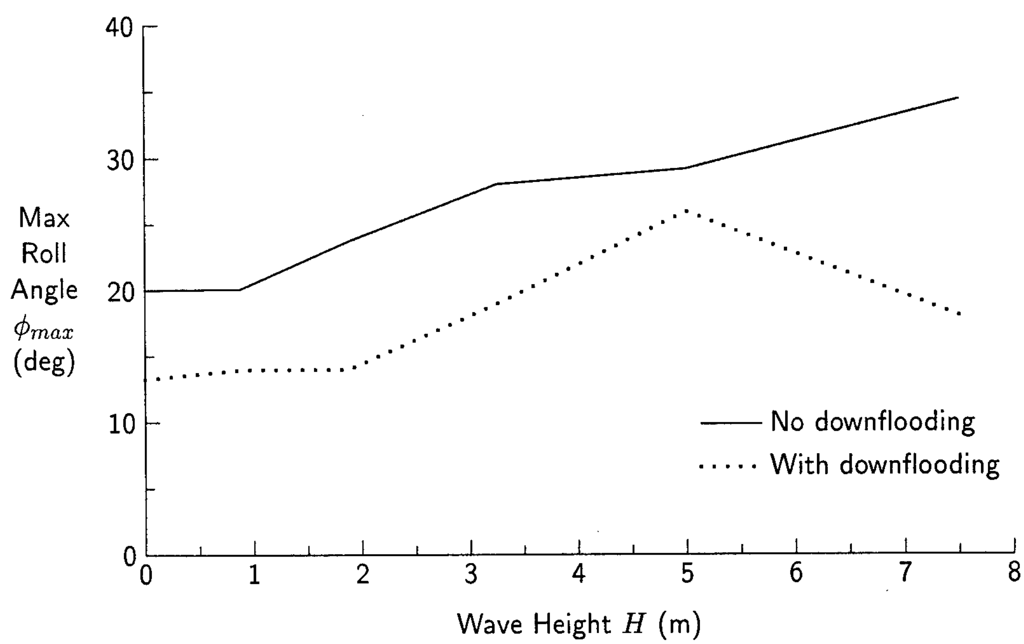

Figure 7: Maximum Absolute Roll Excluding Initial Transients, Initial Beam Seas

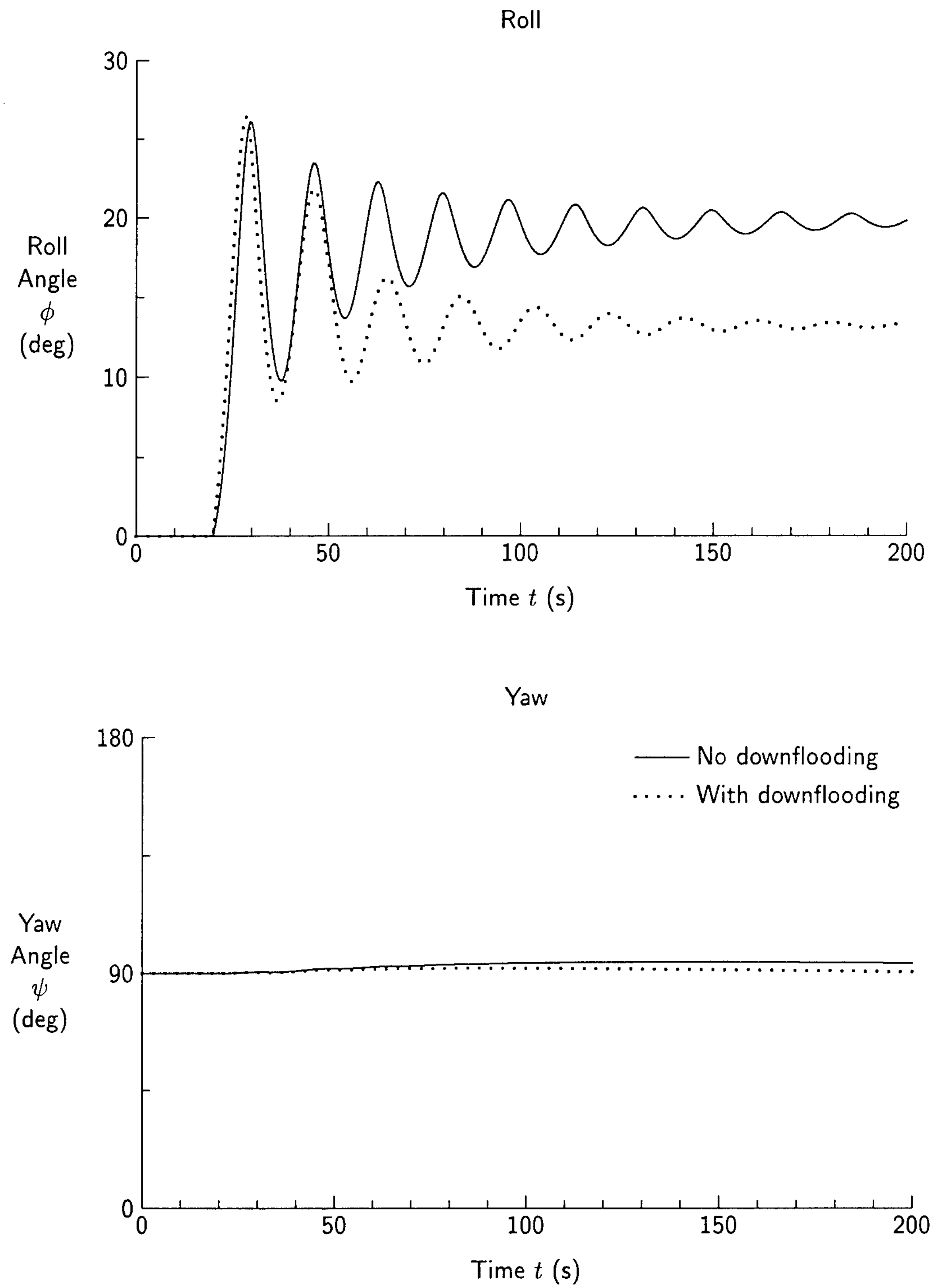

Figure 8: Roll and Yaw Time Series in Calm Water with Damage

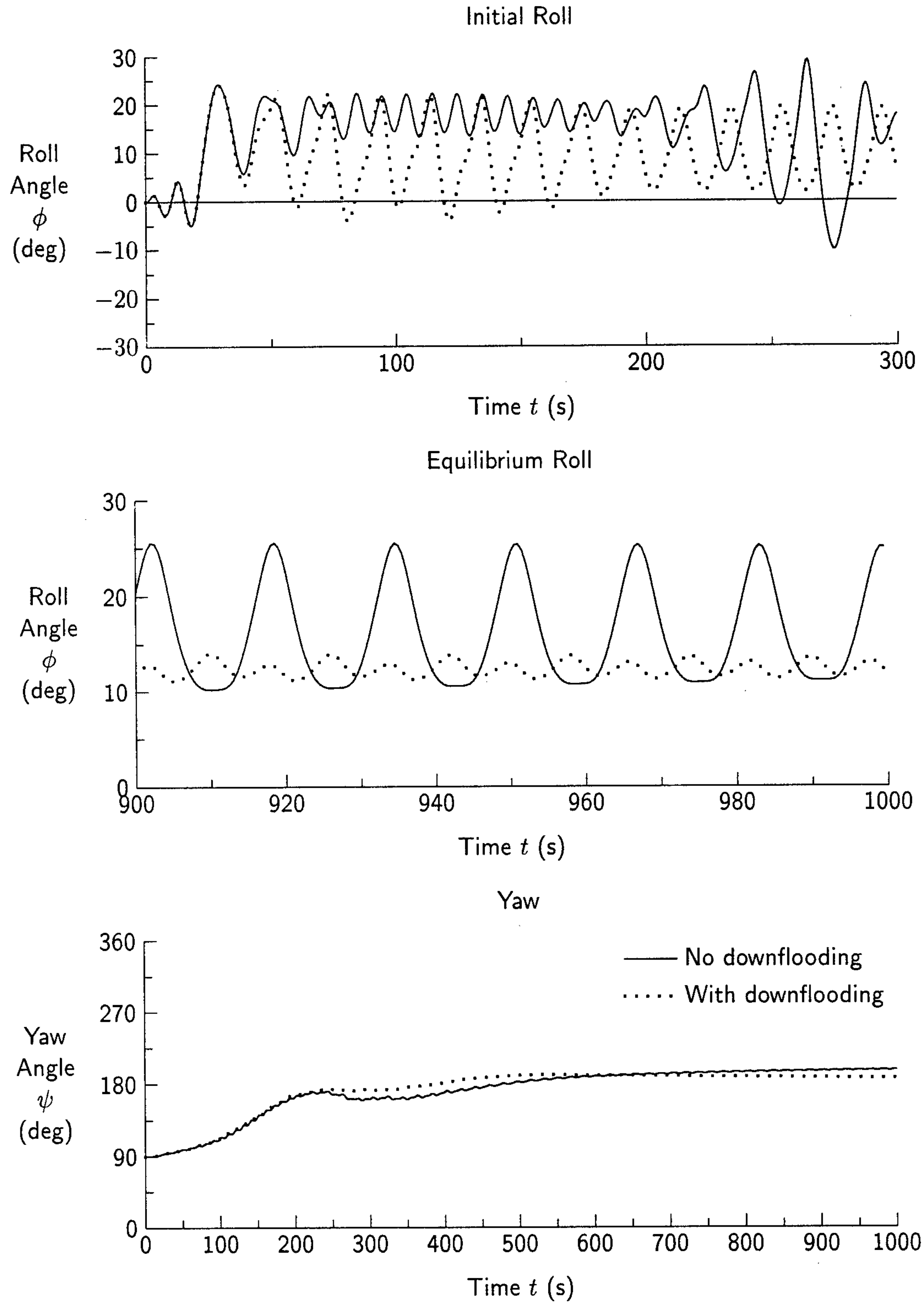

Figure 9: Roll and Yaw, $H = 3.25$ m, $T = 9.7$ s, Initial Beam Seas with Damage to Windward

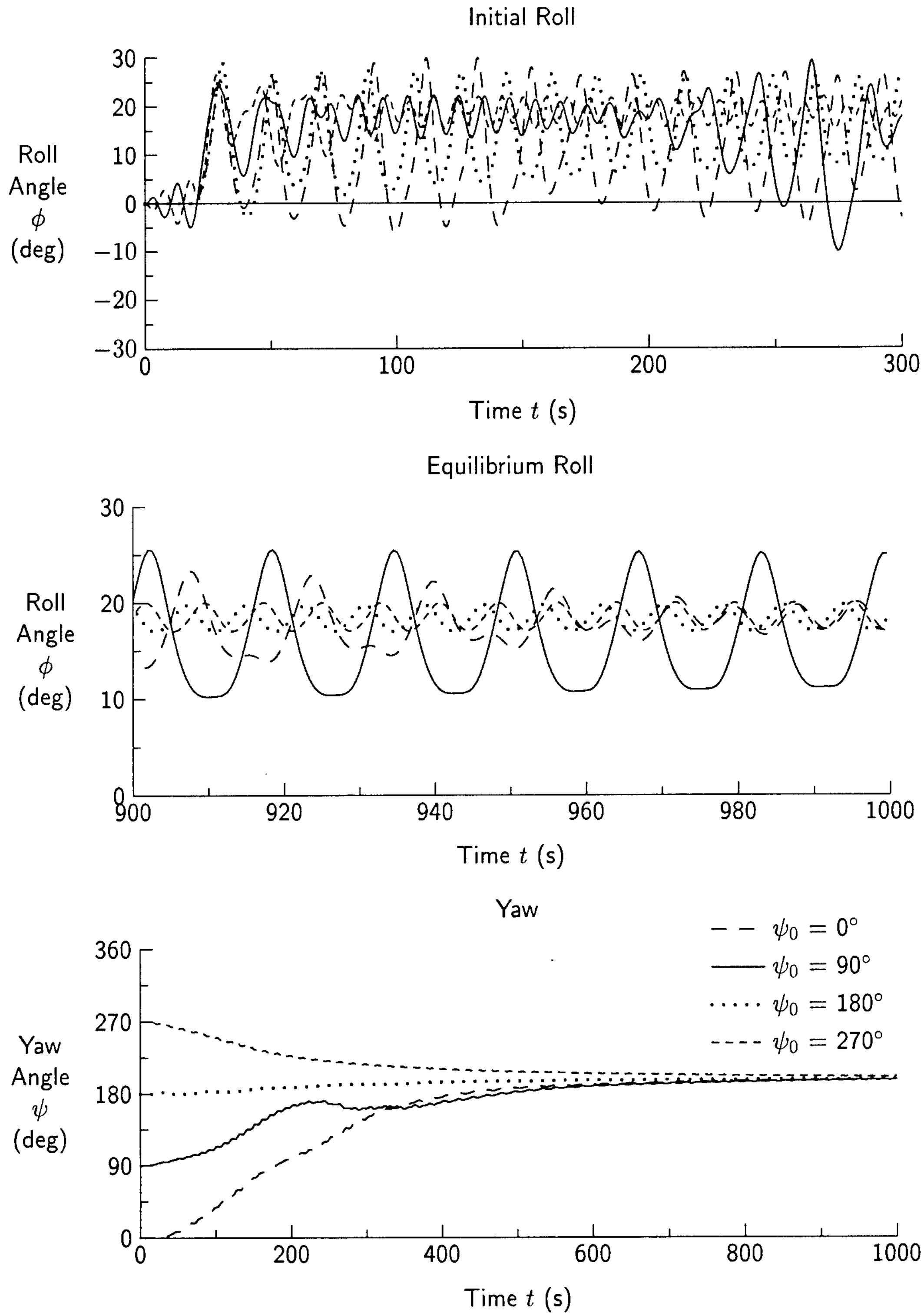

Figure 10: Roll and Yaw in Waves with Damage for Different Initial Headings, H = 3.25 m, T = 9.7 s, Large Damage Hole, No Downflooding

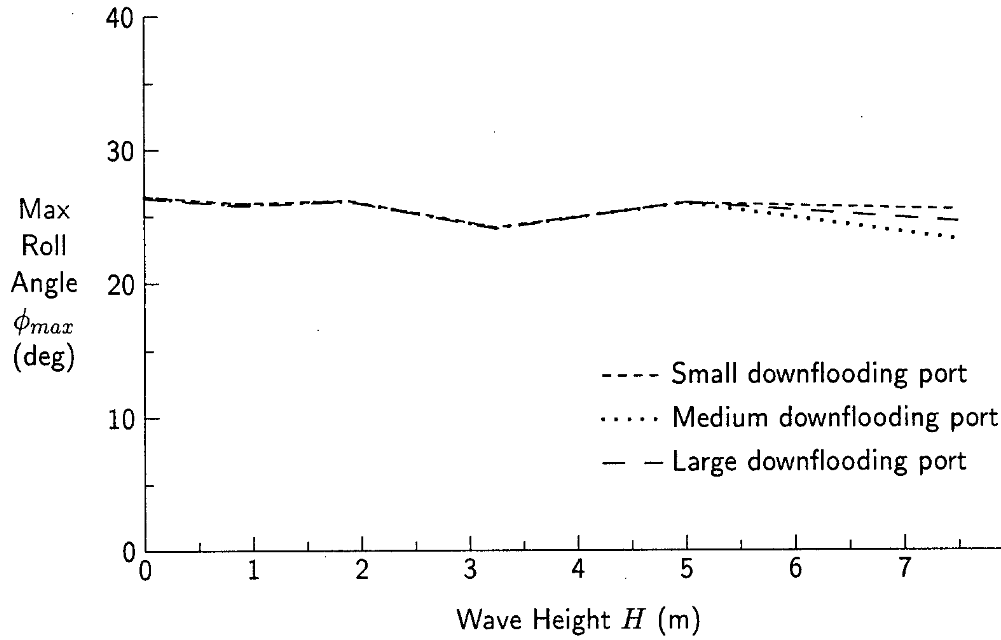

Figure 11: Maximum Absolute Roll Versus Wave Height, Initial Beam Seas with Damage to Windward, Different Downflooding Port Sizes

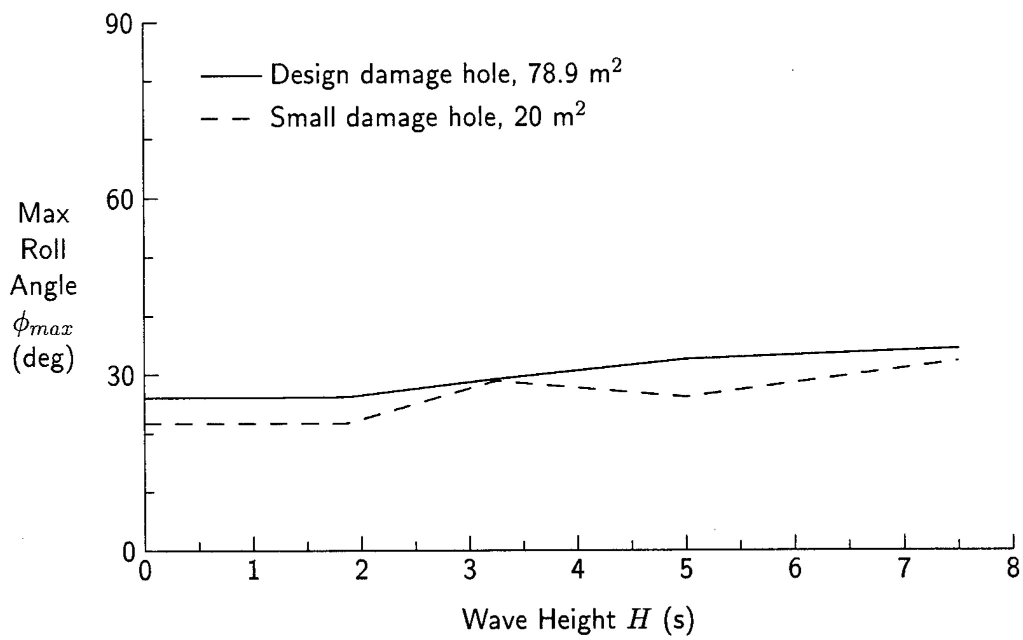

Figure 12: Maximum Absolute Roll Versus Wave Height for Different Damage Hole Sizes, Initial Beam Seas with Damage to Windward

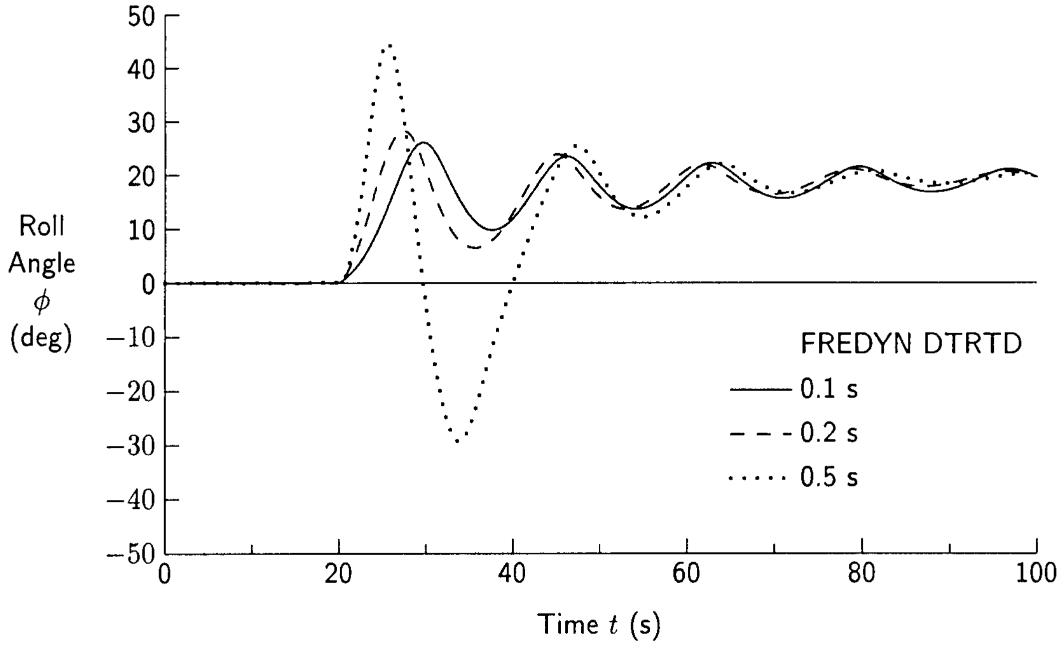

Figure 13: Roll in Calm Water, No Downflooding, Different FREDYN Time Intervals

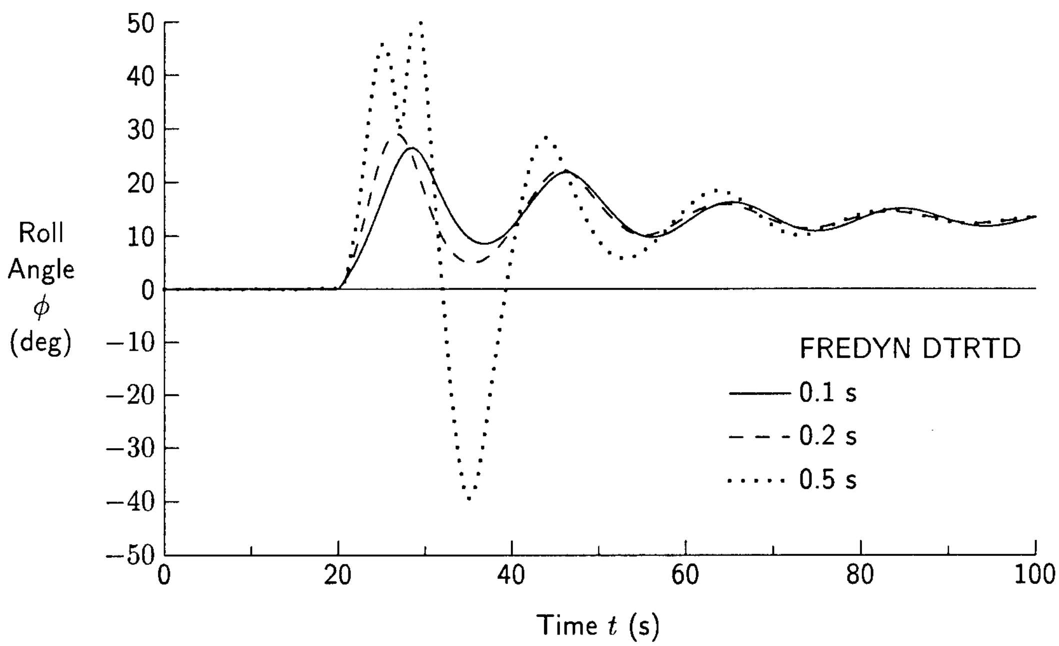

Figure 14: Roll in Calm Water, With Downflooding, Different FREDYN Time Intervals

5 Discussion of Results from Numerical Simulations

It is very encouraging that FREDYN gives nearly identical results to GHS for the static sinkage, list, and trim of the damage case 05AS Operational Light; however, Figures 13 and 14 indicate that the input time step DTRTD should be set to 0.1 s.

When considering the response of a damaged ship in waves, it should be noted that FREDYN ignores sloshing but instead assumes that the water level in each damaged compartment is horizontal. At each time step, FREDYN re-computes the inertial properties of the internal fluid based on its instantaneous position. This assumption of a horizontal water level is possibly acceptable for most damage cases, but further validation is required.

Figures 6 and 7, which give maximum roll responses for a large number of cases, provide the basis for most of the discussion here. At low wave heights, the maximum roll angle occurs immediately after flooding in response to the large initial inflow, as shown in Figure 8. At higher wave heights, Figures 9 and 10 suggest that large oscillatory roll responses can persist long after initiation of flooding.

FREDYN predicts that the ship at zero speed orients its heading into the waves. It should be noted that the prediction of yaw for a ship at zero speed is very difficult, and that the yaw results from FREDYN could be significantly different from actual values. The inherent difficulty with predicting zero speed yaw behaviour arises because it is largely due to second-order effects, which present significant challenges to numerical prediction codes.

The FREDYN simulations indicate the maximum roll angle during a simulation occurs during the initial transient after damage. Downflooding can significantly reduce equilibrium roll motions; however, it has negligible effect on initial transient motions. Within the range of downflooding port sizes investigated here, Figure 11 indicates essentially no difference in resulting roll motions.

6 Suggested Improvements for FREDYN Suite

The present study has provided an excellent opportunity for evaluating the capabilities of FREDYN Version 7.9. This section outlines required and recommended improvements to the FREDYN suite, with the most important points given first.

6.1 Time Step Size for Computation of Inflow

FREDYN predictions for a damaged ship can be very sensitive to the input time step size DTRTD, which controls the time step for computation of fluid inflow rates. FREDYN should ideally incorporate a variable time step size for calculating damage fluid inflow rates. If this is not feasible, then FREDYN should allow for smaller input values of DTRTD (currently DTRTD ≥ 0.1 s) and should also check that DTRTD is sufficiently small given instantaneous flow rates. A relationship such as the following could be used for checking the time step size:

$$\text{DTRTD} \; < \; k \, \frac{\Delta}{\rho \, |Q|} \tag{6.1}$$

where k is a constant, Δ is ship mass displacement, ρ is fluid density, and Q is inflow rate, which can be negative if outflow occurs. For the damaged Iroquois class ship, a time size of 0.1 s was

required for consistent results. A maximum inflow rate of 185 tonnes per second was predicted, suggesting that the constant k should be approximately 0.004 (i.e., the ship mass should change by no more than 0.4 percent per time step).

6.2 Initial Fluid in Intact Ship

The current version of FREDYN is not capable of adequately modelling initial fluid in ship tanks. For example, initial fluid modelled using the FREDYN input record TANK induces sinkage, list, and trim on a ship. FREDYN must be capable of modelling the initial fluid in the ship for the intact condition.

An attempt was made to model initial fluid using the TANK record and by using a counter tank to correct for list. The FREINP input drafts at the fore and aft perpendiculars were modified such that the equilibrium drafts from FREDYN would be correct for the intact condition. Unfortunately, the resulting dynamic properties of the ship caused the ship to behave unrealistically when subjected to an initial roll of 4 degrees in calm water. It is recommended that FREDYN be modified to model correctly the effects of initial fluid in the ship.

6.3 Visualization Capabilities

FREDYN requires visualization capabilities for damaged ships. Visualization is essential for verifying that input compartment geometries are correct. Virtual Reality Modelling Language (VRML) appears to be a promising approach for visualization of hull compartments.

The current FREDYN animation software must be modified to display fluid introduced by damage. This capability would assist in verifying and analysing results from simulations.

6.4 SHCP Input Prepared by OUT2SHCP

SHCP input files prepared by OUT2SHCP should follow guidelines to minimize numerical problems for SHCP. The range of SHCP input trim angles should be reduced significantly from the current range of ±30 degrees. A range of ±15 degrees would likely be sufficient for most ships and damage conditions. The increments between SHCP input roll and pitch angles should be approximately constant.

6.5 Links with Other Damage Stability Codes

The FREDYN suite would be easier to use if it could read compartment properties from other codes such as GHS, which DND currently uses for damage stability calculations. DND plans to obtain this capability by developing a program to convert GHS output files to SHCP output format.

6.6 Improvements to Fortran Coding

The efficiency and readability of the code could be greatly improved using Fortran 90 features. The public domain program CONVERT should be used to convert the source code to free format. The large number of INCLUDE files could be eliminated by converting the COMMON blocks to MODULES, which could be placed in a single file. To reduce memory requirements, larger arrays should be dynamically allocated at run time.

Care should be taken with initialization of variables. In the subroutine version of FREDYN, time should be initialized to zero at the beginning of each subroutine call. The FREDYN subroutine GENSEA should be modified so that wave phases are regenerated if the user provides a new wave phase seed number. The present version of GENSEA uses previously generated wave phases if they exist, and ignores the user input seed number.

6.7 Clarification and Simplification of Input for Damage Holes

Description of a damage hole using the FREDYN input record FLOOD is one of the most difficult aspects of input preparation. Hole definitions should use the same origin as compartment definitions (e.g., aft perpendicular instead of midships).

The FREDYN manual should explain better the convention for entering hole coordinates. The manual says a right-hand rule is used, but it is unclear whether hole points go clockwise or counter-clockwise.

When preparing hole coordinates, significant effort is often required to get all three coordinates (x, y, z) for each hole point. FREDYN should be able to compute y coordinates for the side of the ship if input x and z values are provided by the user.

7 Conclusions

The present study has examined the effectiveness of downflooding ports in reducing maximum roll response of a damaged Iroquois class vessel. The study has also provided an excellent opportunity for trial usage of the FREDYN code, which is still under development.

The most significant finding from this study is the large magnitude of transient roll motions which can occur immediately after damage. Transient motions should be included when evaluating the stability of a damaged ship.

For higher sea states, downflooding ports provide some reduction in predicted maximum roll response of a damaged Iroquois class vessel. In lower sea states, the maximum roll angle occurs immediately after damage and before downflooding has any significant influence on ship motions. The size of the downflooding ports did not make a significant difference over the size range tested. The present findings should be qualified with a statement that the FREDYN damage stability capabilities have not yet been extensively validated and are still under development.

The FREDYN code appears promising for simulating motions of damaged ships in waves; however, much work still needs to be done. The dependence of motion predictions on input time step size should be addressed by more careful consideration of the time interval for computation of damage inflow rates. FREDYN must be modified to correctly model fluid carried by intact ships before the occurrence of damage.

Improved visualization capabilities could enhance the reliability and value of FREDYN simulations. Visualization could help to verify input compartment descriptions for the modelled ship. Animation of internal fluid motions during damage simulations could assist with verification and understanding of simulation results.

The FREDYN suite sometime has difficulties associated with computation of compartment properties. These problems can usually be eliminated by reducing the range of trim angle used as input to SHCP.

Several suggestions have been presented for improving the FREDYN Fortran code. These suggestions would improve the portability, readability, and memory usage of FREDYN.

Improvements to the FREDYN code and documentation could simplify the preparation of input for damage openings. These improvements coupled with suggested visualization capabilities could help to ensure correct input descriptions.

A Selected Input Files for FREDYN Damage Suite

The files in this appendix were used to model damage case 05AS Operational Light, with modification to permit downflooding. For compartments with initial fluid for damage case 05AS Operational Light, input permeabilities have been reduced to model the reduced volume available for flood water.

A.1 SHCP Main Input File Shcpperm.inp

This is the main SHCP input file, which calls other input files.

```
1000                          M5475                  ODXF      30.00        0.25        0.20
C SHCP input file generated from OUT file of program CDAWSP
C Program OUT2SHCP, version  2.1
C Copyright MARIN 1995. Programmed by W.Keukens
C
C DESIGN condition is calculated for an assumed
C Draught of 0.66*DEP metres =     13.200
C
C This file produced by Kevin McTaggart for DDH280 downflooding study,
C September 1999.
C Damage case 05AS modelled with single tank.
C Comparment permeabilities modified to account for initial fluid.
C
C
C
HULL        :HULLDREA.INP
DESIGN
99999999999999999999    20.000
COMP        :COMPPERM.INP
SUB         :SUBDREA.INP
TANK        :TANKONE.INP
STOP
```

A.2 SHCP Input Compartment File Compperm.inp

This file gives geometries of all compartments within the ship.

```
9011T6F-DF01.S 1/4        10.97  44.81  46.63   0.00    2.69 999999    1.83
9012T6F-DF01.S 2/4        10.97  46.63  48.46   0.00    2.73 999999    1.83
9013T6F-DF01.S 3/4        10.97  48.46  52.12   0.00    2.74 999999    1.83
9014PLR27.S    4/4        1-.97  48.36  48.57   0.00    0.14   0.61    1.37
9021T6F-DF02.P 1/4       -10.97  44.81  46.63   0.00    2.69 999999    1.83
9022T6F-DF02.P 2/4       -10.97  46.63  48.46   0.00    2.73 999999    1.83
9023T6F-DF02.P 3/4       -10.97  48.46  52.12   0.00    2.74 999999    1.83
9024T6F-DF02.P 4/4       -1-.97  48.36  48.57   0.00    0.14   0.61    1.37
9031T6G-DF03A.S 1/3       10.97  57.61  58.52   0.00    2.74 999999    2.54
9032T6G-DF03A.S 2/3       10.97  53.95  57.61   0.00    2.74 999999    2.86
9033T6G-DF03A.S 3/3       10.97  52.12  53.95   0.00    2.74 999999    3.51
9041T6G-DF03B.S 1/4       10.97  57.61  58.52   2.74    4.70 999999    2.54
9042T6G-DF03B.S 2/4       10.97  56.69  57.61   2.74    4.70 999999    2.86
9043T6G-DF03B.S 3/4       10.97  53.95  56.69   2.74 999999 999999    2.86
9044T6G-DF03B.S 4/4       10.97  52.12  53.95   2.74 999999 999999    3.51
9051T6G-EXP3.S 1/1        10.97  56.69  58.52   4.70 999999 999999    2.86
9061T6G-DF04A.P 1/3      -10.97  57.61  58.52   0.00    2.74 999999    2.54
9062T6G-DF04A.P 2/3      -10.97  53.95  57.61   0.00    2.74 999999    2.86
9063T6G-DF04A.P 3/3      -10.97  52.12  53.95   0.00    2.74 999999    3.51
9071T6G-DF04B.P 1/4      -10.97  57.61  58.52   2.74    4.70 999999    2.54
9072T6G-DF04B.P 2/4      -10.97  56.69  57.61   2.74    4.70 999999    2.86
9073T6G-DF04B.P 3/4      -10.97  53.95  56.69   2.74 999999 999999    2.86
9074T6G-DF04B.P 4/4      -10.97  52.12  53.95   2.74 999999 999999    3.51
9081T6G-EXP4.P 1/1       -10.97  56.69  58.52   4.70 999999 999999    2.86
9091T6H-SERV1.S 1/2       10.66  78.94  81.23   0.00    3.45 999999    4.19
9092PROP.S      2/2       1-.66  78.94  81.23   2.33    3.16   1.95    2.77
9101T6H-SERV2.P 1/2      -10.97  78.94  81.23   0.00    3.45 999999    4.19
9102T6H-SERV2.P 2/2      -1-.97  78.94  81.23   2.33    3.16   1.95    2.77
9111T6H-DF05.S 1/1        10.66  78.94  81.99   3.45 999999 999999    4.19
9121T6H-DF06.P 1/1       -10.97  78.94  81.99   3.45 999999 999999    4.19
9131T6H-EXP7.S 1/3        10.00  81.99  85.04   6.08 999999   1.93    4.19
9132T6H-EXP7.S 2/3        1-.00  81.99  85.04   6.08    6.70   1.93    2.48
9133T6H-EXP7.S 3/3        1-.00  81.99  85.04   7.16 999999   1.93    3.06
9141T6H-DF07E.S 1/2       10.00  81.99  88.09   3.45 999999 999999    4.19
9142T6H-EXP7.S  2/2       1-.00  81.99  85.04   6.08 999999   1.93    4.19
9151T6J-DF07D.S 1/1       10.00  88.09  91.90   3.45 999999 999999    4.19
9161T6J-DF07C.S 1/2       10.00  88.09  94.18   0.00    3.45 999999    4.19
9162T6J-DF07C.S 2/2       1-.00  88.09  94.18   2.13    3.45 999999    2.26
9171T6J-DF07B.S 1/1       10.00  91.90  97.23   3.45 999999 999999    4.19
9181T6K-DF07A.S 1/1       10.00  97.23 103.02   3.45 999999 999999    4.19
9191T6H-EXP8.P 1/3       -10.97  81.99  85.04   6.08 999999   1.93    4.19
9192T6H-EXP8.P 2/3       -1-.97  81.99  85.04   6.08    6.70   1.93    2.48
```

9193T6H-EXP8.P 3/3	-1-.97	81.99	85.04	7.16	999999	1.93	3.06
9201T6H-DF08E.P 1/2	-10.97	81.99	88.09	3.45	999999	999999	4.19
9202T6H-DF08E.P 2/2	-1-.97	81.99	85.04	6.08	999999	1.93	4.19
9211T6J-DF08D.P 1/1	-10.97	88.09	91.90	3.45	999999	999999	4.19
9221T6J-DF08C.P 1/2	-10.97	88.09	94.18	0.00	3.45	999999	4.19
9222T6J-DF08C.P 2/2	-1-.97	88.09	94.18	2.13	3.45	999999	2.26
9231T6J-DF08B.P 1/1	-10.97	91.90	97.23	3.45	999999	999999	4.19
9241T6K-DF08A.P 1/1	-10.97	97.23	103.02	3.45	999999	999999	4.19
9251T6F-FWDSTRP.C 1/4	00.97	42.98	44.81	0.00	2.62	999999	1.83
9252SUMP24.S 2/4	1-.97	43.08	43.53	1.60	1.83	1.52	1.83
9253SBTUBE.P 3/4	-1-.97	43.72	44.06	2.09	2.44	999999	1.83
9254SUMP25.P 4/4	-1-.97	44.35	44.81	0.00	0.63	1.30	1.83
9261T6H-AFTSTRP.C 1/4	00.97	83.51	87.91	0.00	1.37	999999	0.48
9262T6H-AFTSTRP.C 2/4	00.97	83.51	87.91	0.00A999999		0.48	1.35
9263SEABAY1.P 3/4	-1-.97	83.51	84.28C999999B999999			0.48	1.35
9264SEABAY1.P 4/4	-1-.97	83.51	84.28C999999		1.37	999999	0.48
9271T6K-JP1.P 1/1	-10.97	97.23	103.02	0.00	3.45	999999	4.19
9281T6K-JP2.P 1/1	-10.97	103.02	105.46	0.00	999999	999999	4.19
9291T6K-JP3.S 1/1	10.97	103.02	105.46	0.00	999999	999999	4.19
9301T6E-FW1.S 1/1	10.97	33.07	35.66	0.00	999999	999999	1.83
9311T6E-FW2.P 1/1	-10.97	33.07	35.66	0.00	999999	999999	1.83
9321T6L-FW3.S 1/1	10.97	106.68	110.34	1.37	999999	999999	4.19
9331T6L-FW4.P 1/1	-10.97	106.68	110.34	1.37	999999	999999	4.19
9341T6L-FW5.C 1/2	00.97	106.68	110.34	0.00	1.37	999999	4.19
9342SUMP.P 2/2	-1-.97	109.74	110.34	1.07	1.37	3.99	4.19
9351T5F-BWTANK.S 1/3	11.00	51.51	52.12	3.20D999999		1.37	2.57
9352T5F-BWTANK.S 2/3	11.00	50.90	51.51	3.20	6.71	2.57	4.19
9353T5F-BWTANK.S 3/3	11.00	48.46	50.90	4.95	6.71	2.62	4.19
9361T5F-STBYTK.S 1/4	11.00	48.16	48.46	2.62	4.95	1.52	4.19
9362T5F-STBYTK.S 2/4	11.00	48.16	48.46	3.61	4.06	1.37	1.52
9363T5F-STBYTK.S 3/4	11.00	47.13	48.16	2.62	4.95	1.57	4.19
9364T5F-STBYTK.S 4/4	11.00	46.63	47.13	2.62	4.95	1.79	4.19
9371T6D-SWB1.S 1/3	10.97	28.65	32.31	0.00	999999	999999	1.83
9372T6D-SWB1.S 2/3	10.97	23.16	28.65	1.07	999999	999999	1.83
9373SUMP14.S 3/3	1-.97	24.59	24.90	1.24	1.70	1.52	1.83
9381T6D-SWB2.P 1/3	-10.97	28.65	32.31	0.00	999999	999999	1.83
9382T6D-SWB2.P 2/3	-10.97	23.16	28.65	1.07	999999	999999	1.83
9383SUMP18.P 3/3	-1-.97	31.69	32.31	1.36	1.69	1.54	1.83
9391T6F-SWB3.S 1/10	10.97	42.98	52.12	2.62	999999	999999	4.19
9392T5F-BWTANK.S 2/10	1-.97	51.51	52.12	3.20	6.40	1.37	2.57
9393T5F-BWTANK.S 3/10	1-.97	50.90	51.51	3.20	6.76	2.57	4.19
9394T5F-BWTANK.S 4/10	1-.97	48.46	50.90	4.95	6.71	2.62	4.19
9395T5F-STBYTK.S 5/10	1-.97	48.16	48.46	2.63	4.95	1.37	1.57
9396T5F-STBYTK.S 6/10	1-.97	47.13	48.16	2.62	4.95	1.57	4.19
9397T5F-STBYTK.S 7/10	1-.97	46.63	47.13	2.62	4.95	1.83	4.19

93985FZ3.S 8/10	1-.97	51.51	52.12	2.62	3.20	1.52	4.19
93995FZ3.S 9/10	1-.97	50.90	51.51	2.64	4.95	1.52	3.51
94015FZ3.S 10/10	1-.97	48.46	50.90	2.62	4.95	1.52	4.19
9411T6F-SWB4.P 1/1	-10.97	42.98	52.12	2.62	999999	999999	4.19
9421T6K-SWB5.C 1/1	00.97	105.46	106.68	0.00	999999	999999	4.19
9431T6G-DRAIN.P 1/1	-10.97	58.52	59.44	0.00	1.37	999999	0.61
9441T6G-SUMP.S 1/1	10.97	58.52	59.44	0.00	1.37	999999	0.61
9451T6G-OILYWTR.P 1/2	-10.97	67.97	68.43	2.06	2.74	999999	2.19
9452T6G-OILYWTR.P 2/2	-10.97	68.43	69.80	2.06	2.74	999999	1.97
9461T6G-DRSUMP.P 1/2	-10.97	73.46	75.29	1.37	2.06	999999	0.84
9462T6G-DRSUMP.P 2/2	-10.97	73.46	75.29E999999		2.06	0.84	0.91
9471T6A-VOIDF.C 1/1	00.97	-3.35	4.88	0.00	999999	999999	6.55
9481T6B-VOID3.C 1/1	00.97	4.88	7.31	0.00	999999	999999	1.83
9491T6B-VOID8.C 1/2	00.97	7.31	14.02	0.00	999999	999999	1.83
9492SUMP8.S 2/2	1-.97	13.54	13.94	0.00	0.38	1.52	1.83
9501T6C-VOID13.C 1/2	00.97	14.02	23.16	0.00	999999	999999	1.83
9502SUMP8A.S 2/2	1-.97	14.10	14.50	0.13	0.48	1.50	1.83
9511T6E-COFF18.C	00.97	32.31	33.07	0.00	999999	999999	1.83
9512SBAY18.S	1-.97	32.69	32.69	1.88	2.16	0.21	0.50
9521T6E-VOID24.C 1/6	00.97	41.15	42.98	1.37	4.82	999999	1.83
9522T6E-VOID24.C 2/6	00.97	39.32	41.15	1.37	4.42	999999	1.83
9523T6E-VOID24.C 3/6	00.97	37.49	39.32	1.37	4.19	999999	1.83
9524T6E-VOID24.C 4/6	00.97	36.58	37.49	1.37	4.11	999999	1.83
9525T6E-VOID24.C 5/6	00.97	35.66	36.58	0.00	4.79	999999	1.83
9526PLR22.C 6/6	0-.97	39.20	39.44	2.93	3.17	1.40	1.83
9531C-3A.C 1/1	00.97	0.00	4.88	0.00	999999	6.55	10.74
9541C-2A.C, dummy 1/1	00.97	-30.79	19.39	0.00	999999	8.99	13.26
9551C-MA.C 1/1	00.95	0.00	4.88	0.00	999999	10.74	12.95
9561C-5BA.C 1/1	00.65	4.88	7.31	0.00	999999	1.83	8.99
9571C-5BZ.C 1/2	00.90	7.31	14.02	0.00	999999	1.83	4.19
9572SUMP8.S 2/2	10.90	13.54	13.94	0.00	0.38	1.52	1.83
9581C-4BZ.C 1/1	00.90	7.31	14.02	0.00	999999	4.19	6.55
9591C-3B.C 1/1	00.95	7.31	14.02	0.00	999999	6.55	8.99
9601C-2B.C 1/1	00.95	4.88	14.02	0.00	999999	8.99	12.92
9611C-5C.C 1/2	00.90	14.02	23.16	0.00	999999	1.83	4.19
9612SUMP8A.S 1/2	10.90	14.10	14.50	0.13	0.48	1.50	1.83
9621C-4CA.C 1/1	00.95	14.02	15.85	0.00	999999	4.19	6.55
9631C-4CZ.C 1/3	00.80	15.85	23.16	0.00	999999	4.19	6.55
9632C-4CZ.C 2/3	00.80	15.85	23.16	0.00	2.69	6.55	12.19
96334DA0.C 3/3	0-.80	23.04	23.16	0.00	0.42	11.74	12.19
9641C-3CA0&A1.C 1/2	00.95	14.02	15.85	0.00	2.69	6.55	8.99
9642C-3CA1.S 2/2	10.95	14.02	23.16	2.69	999999	6.55	8.99
9651C-3CA2.P 1/1	-10.95	14.02	23.16	2.69	999999	6.55	8.99
9661C-2CPLENUM.C 1/1	00.95	14.02	15.85	0.00	1.83	11.51	12.55
9671C-2C.C 1/3	00.95	14.02	15.85	0.00	2.69	8.99	12.19

96722CB-Z&A1&2.C 2/3	00.95	14.02	23.16	2.69	999999	8.99	12.19
96732CPLENUM.C 3/3	00.95	14.02	15.85	0.00	1.83	11.51	12.19
9681C-5DA1.S 1/2	10.95	23.16	26.82	1.07	999999	1.83	4.19
9682SUMP14.S 2/2	10.95	24.59	24.90	1.24	1.70	1.52	1.83
9691C-5DA2.C 1/5	00.60	23.16	32.31	0.00	999999	1.83	4.19
9692C-5DA1.S 2/5	1-.60	23.16	26.82	1.07	999999	1.83	4.19
9693SUMP14.S 3/5	1-.60	24.59	24.90	1.24	1.70	1.52	1.83
96945DA0.C 4/5	0-.60	23.16	28.65	0.00	1.07	1.83	4.19
9695SUMP18.P 5/5	-10.60	31.69	32.31	1.36	1.69	1.54	1.83
9701C-5DA0.C 1/2	00.95	23.16	28.65	0.00	1.07	1.60	4.19
9702C-5DA0TOP 2/2	00.95	24.54	25.91	0.00	1.07	4.19	6.55
9711C-4DA1.S 1/7	10.60	29.57	32.31	0.00	999999	4.19	6.55
9712C-4DA1.S 2/7	10.60	26.82	29.57	2.13	999999	4.19	6.55
9713C-4DA1.S 3/7	10.60	25.30	26.82	3.05	999999	4.19	6.55
9714C-4DA1.S 4/7	10.60	24.54	25.30	1.07	999999	4.19	6.55
9715C-4DA1.S 5/7	10.60	23.16	24.54	0.00	999999	4.19	6.55
9716C-4DA1PORT.P 6/7	-10.60	23.16	24.54	0.00	0.29	4.19	6.55
97174DA0.C 7/7	00.60	23.16	23.75	0.00	0.29	4.19	6.55
9721C-4DA0.C 1/4	00.95	23.75	23.88	0.00	0.42	11.74	12.23
9722C-4DA0.C 2/4	00.95	23.16	23.75	0.00	0.29	4.19	11.74
9723C-4DA0.C 3/4	00.95	23.04	23.75	0.00	0.42	11.74	12.23
9731C-4DZ2&A2.P 1/1	-10.94	25.91	32.31	0.00	999999	4.19	6.55
9732C-4DA2.P 2/6	-10.94	24.54	25.91	1.07	999999	4.19	6.55
9733C-4DA2.P 3/6	-10.94	23.16	24.54	0.29	999999	4.19	6.55
9734C-4DA2 4/6	00.94	25.91	26.82	0.00	1.07	4.19	6.55
9735C-4DB&Y.S 5/6	10.94	26.82	29.57	0.00	2.13	4.19	6.55
9736C-4DB&Y.S 6/6	10.94	25.30	26.82	1.07	3.05	4.19	6.55
9741C-3D.C 1/2	00.95	23.16	32.31	0.00	999999	6.55	8.99
97424DA0.C 2/2	0-.95	23.16	23.75	0.00	0.29	6.55	8.99
9751C-2D.C 1/3	00.95	23.16	32.31	0.00	999999	8.99	12.00
97524DA0.C 2/3	0-.95	23.75	23.88	0.00	0.42	11.74	12.00
97534DA0.C 3/3	0-.95	23.16	23.75	0.00	0.29	8.99	11.74
9754C-6EZ.C 1/1	00.90	36.58	42.98	0.00	1.45	999999	4.19
9761C-5E.C 1/3	00.90	32.31	36.58	0.00	999999	1.83	4.19
9762C-5E.C 2/3	00.90	36.58	42.98	1.43	999999	1.24	4.19
9763C-5E.C 3/3	0-.90	36.58	42.98	1.43	4.46	1.24	1.83
9771C-4E.C 1/1	00.87	32.31	42.98	0.00	999999	4.19	6.55
9781C-3E.C 1/1	00.95	32.31	42.98	0.00	999999	6.55	8.99
9791C-2E.C 1/1	00.95	32.31	42.98	0.00	999999	8.99	11.73
9801C-1D&E&F.C 1/1	00.95	26.82	51.82	0.00F	999999	11.73	14.48
9811C-01E&F.C 1/1	00.95	32.31	51.82	0.00F	999999	14.48	17.22
9821C-02E&F.C 1/4	00.95	40.69	51.82	0.00	3.05	17.23	19.65
9822C-02E&F.C 2/4	00.95	38.25	40.69	0.00F	999999	17.23	19.65
9823C-02E&F.C 3/4	00.95	34.75	38.25	0.00	5.49	17.23	19.65
9824C-02E&F.C 4/4	00.95	32.31	34.75	0.00F	999999	17.23	19.65

9831C-5F.C	1/3	00.90	42.98	52.12	0.00	2.62	1.83	4.19
9832SUMP24.S	2/3	10.90	43.08	43.53	1.52	1.83	1.52	1.83
9833SUMP25.P	3/3	-10.90	44.35	44.81	0.00	0.63	1.30	1.83
9841C-5FZ3.S	1/4	10.90	51.51	52.12	2.62	3.20	1.52	4.19
9842C-5FZ3.S	2/4	10.90	50.90	51.51	2.64	4.95	1.52	3.15
9843C-5FZ3.S	3/4	10.90	50.90	51.51	2.64	3.20	3.15	4.19
9844C-5FZ3.S	4/4	10.90	48.46	50.90	2.62	4.95	1.52	4.19
9851C-4F.C	1/1	00.95	42.98	52.12	0.00	999999	4.19	6.55
9861C-3F.C	1/1	00.95	42.98	52.12	0.00	999999	6.55	8.99
9871C-2F.C	1/1	00.95	42.98	52.12	0.00	999999	8.99	11.60
9881C-6GY.C	1/25	00.87	52.12	67.97	0.00	999999	999999	6.55
9882SEABAY2.C	2/25	0-.87	66.22	67.97	0.00	2.06	999999	0.99
9883T6G-DF03A.S	3/25	1-.87	57.61	58.52	0.00	2.74	999999	2.54
9884T6G-DF03A.S	4/25	1-.87	53.95	57.61	0.00	2.74	999999	2.86
9885T6G-DF03A.S	5/25	1-.87	52.12	53.95	0.00	2.74	999999	3.51
9886T6G-DF04A.P	6/25	-1-.87	57.61	58.52	0.00	2.74	999999	2.54
9887T6G-DF04A.P	7/25	-1-.87	53.95	57.61	0.00	2.74	999999	2.86
9888T6G-DF04A.P	8/25	-1-.87	52.12	53.95	0.00	2.74	999999	3.51
9889T6G-DF03B.S	9/25	1-.87	57.61	58.52	2.74	4.70	999999	2.54
9890T6G-DF03B.S	10/25	1-.87	56.69	57.61	2.74	4.70	999999	2.86
9891T6G-DF03B.S	11/25	1-.87	53.95	56.69	2.74	999999	999999	2.86
9892T6G-DF03B.S	12/25	1-.87	52.12	53.95	2.74	999999	999999	3.51
9893T6G-DF04B.P	13/25	-1-.87	57.61	58.52	2.74	4.70	999999	2.54
9894T6G-DF04B.P	14/25	-1-.87	56.69	57.61	2.74	4.70	999999	2.86
9895T6G-DF04B.P	15/25	-1-.87	53.95	56.69	2.74	999999	999999	2.86
9896T6G-DF04B.P	16/25	-1-.87	52.12	53.95	2.74	999999	999999	3.51
9897T6G-EXP3.S	17/25	1-.87	57.61	58.52	4.70	999999	999999	2.86
9898T6G-EXP3.S	18/25	1-.87	56.69	57.61	4.70	999999	999999	2.86
9899T6G-EXP4.P	19/25	-1-.87	57.61	58.52	4.70	999999	999999	2.86
9900T6G-EXP4.P	20/25	-1-.87	56.69	57.61	4.70	999999	999999	2.86
9901T6G-DRAIN.P	21/25	-1-.87	58.52	59.44	0.00	1.37	999999	0.61
9902T6G-SUMP.S	22/25	1-.87	58.52	59.44	0.00	1.37	999999	0.61
99036GYUPTAKE.C	23/25	00.95	57.91	63.09	0.00	3.20	6.55	11.20
99046GYINTAKE.C	24/25	00.95	52.12	55.78	0.00	3.81	6.55	8.99
99056GYINTAKE.C	25/25	00.95	52.12	55.78	0.00	2.53	8.99	13.56
9911C-3GA.C	1/3	00.95	52.12	67.97	0.00	999999	6.55	8.99
99126GYUPTAKE.C	2/3	0-.95	57.91	63.09	0.00	3.20	6.55	8.99
99136GYINTAKE.C	3/3	0-.95	52.12	55.78	0.00	3.81	6.55	8.99
9921C-2G.C	1/3	00.95	52.12	67.97	0.00	999999	8.99	11.73
99226GYINTAKE.C	2/3	0-.95	52.12	55.78	0.00	2.44	8.99	11.73
99236GYUPTAKE.C	3/3	0-.95	57.91	63.09	0.00	3.20	8.99	11.73
9931C-6GZ.C	1/5	00.85	67.97	78.94	0.00	999999	999999	6.55
99326GZUPTAKE.C	2/5	0-.85	67.97	71.63	0.00	1.07	6.55	6.55
9933T6G-OILYWTR.P	3/5	-1-.85	67.97	68.43	2.06	2.74	999999	2.19
9934T6G-OILYWTR.P	4/5	-1-.85	68.43	69.80	2.06	2.74	999999	1.74

9935T6G-DRSUMP.P 5/5	-1-.85	73.46	75.29	1.37	2.06	999999	0.91
9941C-3GZ.C 1/2	00.95	67.97	78.94	0.00	999999	6.55	8.99
99426GZUPTAKE.C 2/2	0-.95	67.97	71.63	0.00	1.07	6.55	8.99
9951C-01GA0.C 1/2	00.60	70.41	72.97	0.00	0.91	15.70	18.28
9952C-01GA0.C 2/2	00.60	72.97	73.46	0.00	0.84	15.70	18.28
9961C-5HZ.C 1/3	00.90	81.23	88.09	0.00	3.45	999999	4.19
9962T6H-AFTSTRP.C 2/3	0-.90	83.51	88.09	0.00	1.37	999999	1.35
99634H0.C 3/3	0-.90	87.50	88.09	0.00	0.29	3.35	4.19
9971C-4H.C 1/2	00.95	78.94	88.09	0.00	999999	4.19	6.55
99724H0.C 2/2	00.95	87.50	88.09	0.00	0.29	4.19	6.55
9981C-4H0.C 1/3	00.95	87.19	88.40	0.00	0.61	10.44	11.73
9982C-4H0.C 2/3	00.95	87.38	88.21	0.00	0.42	10.13	10.44
9983C-4H0.C 3/3	00.95	87.48	88.09	0.00	0.29	3.35	10.13
9991C-3H.C 1/2	00.95	78.94	88.09	0.00	999999	6.55	8.99
99924H0.C 2/2	00.95	87.50	88.09	0.00	0.29	6.55	8.99
8011C-2HZ6.P 1/1	-10.95	85.04	88.09	4.11	999999	8.99	11.60
8021C-2HZ.S 1/3	10.93	82.88	84.28	3.81	999999	8.99	11.73
8022C-2HZ.S 2/3	10.93	81.99	82.88	4.11	999999	8.99	11.73
8023C-2HZ1.S 3/3	10.93	84.28	88.09	0.00	999999	8.99	11.73
8031C-2G&H.C 1/9	00.95	67.97	88.09	0.00	999999	8.99	11.73
8032C-2HZ6.P 2/9	-1-.95	85.04	88.09	4.11	999999	8.99	11.73
8033C-2HZ.S 3/9	1-.95	82.88	84.28	3.81	999999	8.99	11.73
8034C-2HZ.S 4/9	1-.95	81.99	82.88	4.11	999999	8.99	11.73
8035C-2HZ1.S 5/9	1-.95	84.28	88.09	0.00	999999	8.99	11.73
80366GZUPTAKE.C 6/9	0-.95	67.97	71.63	0.00	1.07	8.99	11.73
80374H0.C 7/9	0-.95	87.50	88.09	0.00	0.42	8.99	10.44
80384H0.C 8/9	0-.95	87.38	87.50	0.00	0.61	10.13	15.24
80394H0.C 9/9	0-.95	87.18	87.38	0.00	0.61	10.44	15.24
8041C-6JZ0.C 1/2	00.90	94.18	97.23	0.00	3.45	999999	4.19
8042T6J-DF07C.S 2/2	1-.90	94.18	97.23	2.13	3.45	999999	2.26
8051C-4J.C 1/1	00.95	88.09	97.23	0.00	999999	4.19	6.55
8061C-3J.C 1/1	00.95	88.09	97.23	0.00	999999	6.55	8.99
8071C-2JA.C 1/2	00.70	88.09	93.57	0.00G999999		8.99	11.73
80724H0.C 2/2	0-.70	88.09	88.40	0.00	0.61	10.44	11.73
8081C-2J&K.C 1/2	00.95	93.57	100.58	0.00H999999		8.99	11.73
8082C-2JZ2.P 2/2	-10.95	93.57	95.40H999999I999999			8.99	11.69
8091C-6KA1.S 1/1	10.90	97.23	103.02	0.00	3.45	999999	4.19
8101C-4K.C 1/1	00.95	97.23	106.68	0.00	999999	4.19	6.55
8111C-3K.C 1/1	00.95	97.23	106.68	0.00	999999	6.55	8.99
8121C-4LA.C 1/3	00.95	106.68	110.34	0.00	999999	4.19	6.55
81224LA-AFT.C 2/3	00.95	110.34	111.40	0.00	999999	4.65	6.55
8123SUMP.P 3/3	-10.95	109.74	110.34	1.07	1.37	3.99	4.19
8131C-3LA.C 1/3	00.95	106.68	111.40	0.00	999999	6.55	8.99
8132MID.S 2/3	10.95	111.40	115.67	2.82	999999	6.55	8.99
8133AFT.S 3/3	10.95	115.67	117.96	1.98	999999	6.55	8.99

```
8141C-4LY&C.C 1/6           00.88 114.30 117.96  0.00 999999 999999   6.55
8142STORE.C   2/6           00.88 112.47 114.30  1.37 999999 999999   6.55
8143STOREF.C  3/6           00.88 111.40 112.47  1.37 999999   4.65   6.55
8144SAMA.C    4/6           00.88 112.47 114.30  0.00   1.37 999999   6.55
8145SAMF.C    5/6           00.88 111.40 112.47  0.00   1.37   4.65   6.55
8146VOID.C    6/6           00.88 110.34 112.47  0.00 999999 999999   4.65
8151C-4LZ.C  1/1            00.90 117.96 123.44  0.00 999999 999999   6.55
8161C-3LY2.P 1/1           -10.90 111.40 119.79  1.98 999999   6.55   8.99
8162         1/2           -1-.90 118.64 119.79  1.98   2.44   7.47   8.69
8171C-3LZ1.S 1/1            10.95 117.96 123.44  1.98 999999   6.55   8.99
8181C-3LZ2.P 1/1           -10.95 119.79 123.44  1.98 999999   6.55   8.99
8182                       -10.95 119.79 120.32  1.98   2.44   7.47   8.69
8200Tank100cntr            -11.00  84.65  94.65  2.90   3.90   1.90   2.90
END
```

A.3 SHCP Input Subdivision File Subdrea.inp

This file gives subdivisions composed of compartments described in the previous input file. Subdivision 100 includes all compartments free to flood for damage case 05AS Operational Light.

```
6009 9091 9092
6011 9111
6013 9131 9132 9133
6014 9141 9142
6015 9151
6016 9161 9162
6017 9171
6018 9181
6054 8091
4009 9971 9972
4011 8051
4012 8101
3010 9991 9992
3011 8061
3012 8111
2010 8021 8022 8023
2011 8031 8032 8033 8034 8035 8036 8037 8038 8039
2012 8071 8072
2013 8081 8082
6026 9261 9262 9263 9264
6053 8041 8042
5012 9961 9962 9963
2009 8011
 100 9091 9092 9111 9131 9132 9133 9141 9142 9151 9161 9162 9171 9181 8091 1
9971 9972 8051 8101 9991 9992 8061 8111 8021 8022 8023 8031 8032 8033 8034 1
8035 8036 8037 8038 8039 8071 8072 8081 8082
 101 8200
6999 9091 9092 9111 9131 9132 9133 9141 9142 9151 9161 9162 9171 9181 8091
4999 9971 9972 8051 8101
3999 9991 9992 8061 8111
2999 8021 8022 8023 8031 8032 8033 8034 8035 8036 8037 8038 8039 8071 8072 1
8081 8082
END
```

A.4 SHCP Input Tank Property Computation File Tankone.inp

This file controls computation of tank fluid properties for different values of heel, trim, and percentage full.

```
 19 21  0
   -89.0    -80.0    -70.0    -60.0    -50.0    -40.0    -30.0    -20.0    -10.0      0.0
    10.0     20.0     30.0     40.0     50.0     60.0     70.0     80.0     89.0
   -10.0     -9.0     -8.0     -7.0     -6.0     -5.0     -4.0     -3.0     -2.0      1.0
     0.0      1.0      2.0      3.0      4.0      5.0      6.0      7.0      8.0      9.0
    10.0
C Subdivision 100, flooded tanks for damage case 05AS
  2 21  0 SUB    100
  100
     0.1      5.0     10.0     15.0     20.0     25.0     30.0     35.0     40.0     45.0
    50.0     55.0     60.0     65.0     70.0     75.0     80.0     85.0     90.0     95.0
    99.9
C Subdivision 5012, downflooding tank
  2 21  0 SUB   5012
 5012
     0.1      5.0     10.0     15.0     20.0     25.0     30.0     35.0     40.0     45.0
    50.0     55.0     60.0     65.0     70.0     75.0     80.0     85.0     90.0     95.0
    99.9
C Subdivision 6053, downflooding tank
  2 21  0 SUB   6053
 6053
     0.1      5.0     10.0     15.0     20.0     25.0     30.0     35.0     40.0     45.0
    50.0     55.0     60.0     65.0     70.0     75.0     80.0     85.0     90.0     95.0
    99.9
END
```

A.5 FREINP Input File Freinp.inp

This file controls computation of ship hydrodynamic properties before running FREDYN.

```
COMMENT   DDH280 Operational Light for downflooding study, October 1999
DRAFTS    5.059    5.019    6.489    4.481
WEIGHT    1025.    5.72     27.29    27.29    6.393    0.034
RESIST    2.572    0.239E5
RESIST    5.144    0.876E5
RESIST    7.717    2.383E5
RESIST    10.289   6.552E5
RESIST    12.861   9.266E5
PROP      4.318    0.011    0.091
KT        0.00     0.6000
KT        0.30     0.4660
KT        0.60     0.3920
KT        0.90     0.2725
KT        1.00     0.2279
KT        1.10     0.1835
KT        1.20     0.1374
KT        1.30     0.0867
RUDDER-1  -56.10   0.00     2.47     4.60     3.10     0.05     90.0
RUDDER-2  0
BILGE-1   0.61     7        14       1
BILGE-2   2250.    8.60     10.0     8.48     37.0
WSPFNM    wspl.dat
WINDAGE   534.6    0.0      526.5    0.0      8.68     -7.84
```

A.6 FREDYN Input File Freh325.inp

This is the FREDYN input file including downflooding for a wave height of 3.25 m and wave period of 9.7 s.

```
COMMENT   DDH280 downflooding study, Operational Light
COMMENT   Damage case 05AS modelled with one large subdivision
COMMENT   Downflooding into compartments 5012 and 6053
COMMENT   Large damage hole
COMMENT   H = 3.25 m
TNKFNM    cpmprm.dat
DATFNM    fridam.dat
OPTION    DAMAOP    PRIWAV    NOLIST
SIMTIME   1000.0    0.0       20.0
INITPOS   0.00      0.000     0.000     0.000     0.0       90.00     90.00
INITVEL   0.0       0.0       0.0       0.0       0.0       0.0
RPMPROP   0.0       0.0
SIMPAR              5                   150       0.1
DELO      0.000
DELDC     9.000
DELGO     0.0
MAN       1
WAVE1     3.25      9.7       1         0
COMMENT   Tanks with openings to the sea
FLOOD1    SUB    100          19.7      0.6       0.0
FLOOD2    -27.432   7.4       6.643     -32.004   7.4       7.01
FLOOD3    -32.004   7.2       4.267     -22.860   7.4       4.267
FLOOD1    SUB    100          19.7      0.6       0.0
FLOOD2    -22.860   7.4       4.267     -32.004   7.2       4.267
FLOOD3    -32.004   4.8       1.524     -27.432   5.5       1.892
FLOOD1    SUB    100          19.7      0.6       0.0
FLOOD2    -32.004   7.4       7.01      -36.576   7.2       6.643
FLOOD3    -41.148   6.4       4.267     -32.004   7.2       4.267
FLOOD1    SUB    100          19.7      0.6       0.0
FLOOD2    -32.004   7.2       4.267     -41.148   6.4       4.267
FLOOD3    -36.576   4.0       1.892     -32.004   4.8       1.524
COMMENT   Openings to downflooding tanks
FLOOD1    SUB    100SUB   5012 0.292    0.6       0.0
FLOOD2    -21.8     -3.3      4.191     -21.2     -3.3      4.191
FLOOD3    -21.2     -2.7      4.191     -21.8     -2.7      4.191
FLOOD1    SUB    100SUB   5012 0.292    0.6       0.0
FLOOD2    -21.8     2.7       4.191     -21.2     2.7       4.191
FLOOD3    -21.2     3.3       4.191     -21.8     3.3       4.191
FLOOD1    SUB    100SUB   5012 0.292    0.6       0.0
FLOOD2    -27.3     -3.3      4.191     -26.7     -3.3      4.191
FLOOD3    -26.7     -2.7      4.191     -27.3     -2.7      4.191
```

```
FLOOD1    SUB     100SUB    5012 0.292    0.6       0.0
FLOOD2    -27.3      2.7        4.191    -26.7      2.7         4.191
FLOOD3    -26.7      3.3        4.191    -27.3      3.3         4.191
FLOOD1    SUB     100SUB    6053 0.292    0.6       0.0
FLOOD2    -36.3     -3.3        4.191    -35.7     -3.3         4.191
FLOOD3    -35.7     -2.7        4.191    -36.3     -2.7         4.191
FLOOD1    SUB     100SUB    6053 0.292    0.6       0.0
FLOOD2    -36.3      2.7        4.191    -35.7      2.7         4.191
FLOOD3    -35.7      3.3        4.191    -36.3      3.3         4.191
```

B FREINP and FREDYN Output Files

B.1 FREINP Output File Freinp.out

```
                                F R E I N P                                DATE : 22/11/1999
                                ===========                                TIME : 11:30:31

                                Revision 7.9

DETERMINATION OF THE HYDRODYNAMIC COEFFICIENTS FOR THE FRIGATE SIMULATION PROGRAM FREDYN
----------------------------------------------------------------------------------------
(MANOEUVRING BEHAVIOUR OF A FRIGATE IN WAVES AND WIND WITH DAMAGED COMPARTMENTS)
--------------------------------------------------------------------------------




**** N O T I C E ****

This program has been developed by the Maritime Research Institute Netherlands (MARIN)
MARIN does not assume any responsibility for the validity, accuracy or applicability of
any result obtained from this computer program.
For a detailed description reference is made to:

          * FREDYN 7.7 User's Guide *




Suggestions and comments on the program and documentation are welcome.
Any errors encountered should be brought to our attention.

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```

```
*********************************** WSPL-FILE **********************************
Jobid              =
Date               = 11/22/1999
Time               = 11:26:58
Project            = M5475
PP-RECORDS :
    100.  121310.    7620.   20000.        0.        0.        0.        0.   60655.
   6066.       -1.  121310.       -1.   20000.        0.     7620.    13200.       0.

*********************************** END OF SUMMARY WSPL-FILE *******************
```

```
                             Summary of input records
*******************************************************************************************
Record no.         *          *          *          *          *          *          *          *
*******************************************************************************************

        0          COMMENT    |DDH280 Ope|rational L|ight for d|ownfloodin|g study, O|ctober 199|9
        1          DRAFTS     |5.059     |5.019     |6.489     |4.481     |          |          |
        2          WEIGHT     |1025.     |5.72      |27.29     |27.29     |6.393     |0.034     |
        3          RESIST     |2.572     |0.239E5   |          |          |          |          |
        4          RESIST     |5.144     |0.876E5   |          |          |          |          |
        5          RESIST     |7.717     |2.383E5   |          |          |          |          |
        6          RESIST     |10.289    |6.552E5   |          |          |          |          |
        7          RESIST     |12.861    |9.266E5   |          |          |          |          |
        8          PROP       |4.318     |0.011     |0.091     |          |          |          |
        9          KT         |0.00      |0.6000    |          |          |          |          |
       10          KT         |0.30      |0.4660    |          |          |          |          |
       11          KT         |0.60      |0.3920    |          |          |          |          |
       12          KT         |0.90      |0.2725    |          |          |          |          |
       13          KT         |1.00      |0.2279    |          |          |          |          |
       14          KT         |1.10      |0.1835    |          |          |          |          |
       15          KT         |1.20      |0.1374    |          |          |          |          |
       16          KT         |1.30      |0.0867    |          |          |          |          |
       17          RUDDER-1   |-56.10    |0.00      |2.47      |4.60      |3.10      |0.05      |90.0
       18          RUDDER-2   |0         |          |          |          |          |          |
       19          BILGE-1    |0.61      |7         |14        |1         |          |          |
       20          BILGE-2    |2250.     |8.60      |10.0      |8.48      |37.0      |          |
       21          WSPFNM     |wspl.dat  |          |          |          |          |          |
       22          WINDAGE    |534.6     |0.0       |526.5     |0.0       |8.68      |-7.84     |

*******************************************************************************************

 Position of foremost frame does not match LPP
 Position of foremost frame does not match LPP
```

DDH280 Operational Light for downflooding study, October 1999

REVIEW OF INPUT

Hull form M5475 on file wspl.dat made on 11/22/1999

Ship dimensions

Length between perpendiculars	:	121.31	(m)	
Maximum width on waterline	:	15.22	(m)	
Depth amidships	:	20.00	(m)	
Design draft	:	5.04	(m)	intact
Draft at FPP	:	4.48	(m)	estimated damaged wl
Draft at APP	:	6.49	(m)	estimated damaged wl
Water density	:	1025.00	(kg/m**3)	
X moment of inertia	:	0.17E+09	(kg*m**2)	intact
Y moment of inertia	:	0.38E+10	(kg*m**2)	intact
Z moment of inertia	:	0.38E+10	(kg*m**2)	intact
X location CoG w.r.t. 0	:	-3.70	(m)	intact
Z location CoG w.r.t. 0	:	-0.91	(m)	COG intact wrt damaged wl
GM reduction of bunkers	:	0.03	(m)	

DDH280 Operational Light for downflooding study, October 1999

REVIEW OF INPUT (continued)

Propeller data

Propeller number 1

Diameter of propeller	4.32	(m)
Wake fraction	0.01	(-)
Thrust deduction fraction	0.09	(-)
Thrust coefficient KT0	0.59	(-)
Thrust coefficient KT1	-0.39	(-)
Thrust coefficient KT2	0.09	(-)
Thrust coefficient KT3	-0.06	(-)

```
PROGRAM  F R E I N P                 DATE : 22/11/1999   TIME :   11:30:31          PAGE :   3


DDH280 Operational Light for downflooding study, October 1999


          REVIEW OF INPUT  (continued)


Rudder data
-----------

                                    Rudder number           1


Type (Rudder or Skeg)                             Rudder
X location of COG rel. to origin                  -56.10 (m)
Y location of COG rel. to origin                    0.00 (m)
Z location of COG rel. to origin (dam.)             3.94 (m)
Height of rudder                                    4.60 (m)
Average chord of rudder                             3.10 (m)
Wake fraction                                       0.05 (-)
Heeling angle between rudder blade and Y           90.00 (deg)
Index of propeller in front of rudder                  0 (-)



PROGRAM  F R E I N P                 DATE : 22/11/1999   TIME :   11:30:31          PAGE :   4


DDH280 Operational Light for downflooding study, October 1999


Data for bilge keel forces
--------------------------

                MABK   0.00000 (kg*m)
                MPBK   0.00000 (kg*m**2)
                LBK    42.4585 (m)
```

DDH280 Operational Light for downflooding study, October 1999

Sectional data at input draught (damaged)

STATION No. [-]	DRAFT [m]	WIDTH [m]	AREA [m**2]	FREEBOARD [m]
1	2.26	10.91	22.45	13.51
2	2.80	12.08	30.39	13.61
3	3.43	12.99	39.10	13.71
4	4.57	13.70	49.00	13.81
5	6.09	14.27	59.04	13.91
6	5.99	14.70	66.13	14.01
7	5.89	15.00	70.91	14.11
8	5.79	15.18	73.53	14.21
9	5.69	15.24	74.23	14.31
10	5.59	15.24	73.58	14.41
11	5.48	15.22	71.72	14.52
12	5.38	15.09	68.70	14.62
13	5.28	14.72	63.91	14.72
14	5.18	13.89	57.00	14.82
15	5.08	12.57	48.58	14.92
16	4.98	10.82	39.07	15.02
17	4.88	8.76	29.41	15.12
18	4.78	6.53	20.05	15.22
19	4.68	4.29	11.83	15.32
20	4.30	2.16	4.91	15.42
21	0.26	0.19	0.15	15.52

DDH280 Operational Light for downflooding study, October 1999

Waterlines used for calculation based on estimated damaged wl

ZWL (above keelline) [m]	DISP.VOLUME [m**3]	LCB (w.r.t. APP) [m]
-2.572	0.000	0.000
-0.881	0.000	0.000
0.611	144.736	66.819
1.904	1108.891	62.685
2.998	2272.615	60.608
3.894	3393.675	58.908
4.590	4352.369	57.649
5.087	5061.501	56.974
5.386	5493.157	56.658
5.485	5637.947	56.565
5.689	5936.568	56.393
6.301	6839.948	55.997
7.320	8374.696	55.627
8.747	10581.978	55.480
10.582	13520.343	55.636
12.825	17242.547	56.077
15.476	21691.371	56.547
18.534	26825.385	56.888
22.000	29287.576	57.010

DDH280 Operational Light for downflooding study, October 1999

Hydrostatics for intact ship

```
DISPLACEMENT =   4997.000 m3
KG           =      6.393 m
GM-dry       =      1.170 m
GM-fluid     =      1.136 m
RPS          =      180.0 deg
TOTDST       =      6.352 m*rad
```

angle [deg]	draught [m]	KNphi [m]	GZ [m]	TRIM [m]	KN*sin(PHI) [m]	DynStb [m*rad]	SHCP-draft [m]
0.100	5.039	7.563	0.002	-0.043	0.013	0.000	5.039
10.000	5.023	7.477	0.188	-0.031	1.298	0.016	5.002
20.000	4.960	7.553	0.397	0.038	2.583	0.067	4.868
30.000	4.794	7.640	0.623	0.209	3.820	0.162	4.546
40.000	4.414	7.712	0.848	0.457	4.957	0.285	3.810
50.000	3.634	7.841	1.109	0.677	6.007	0.457	2.101
60.000	2.044	8.199	1.564	0.788	7.100	0.685	-2.305
70.000	-1.733	9.091	2.536	0.821	8.543	1.039	-17.365
80.000	-14.403	10.442	3.987	0.772	10.283	1.601	-113.366
89.000	-244.803	11.479	5.085	0.581	11.477	2.314	-14386.835

GM according to small angle stability considerations :

```
GM-dry   =    1.050 m
GM-fluid =    1.016 m
```

DDH280 Operational Light for downflooding study, October 1999

General characteristics damaged ship

DRAFT	5.48500	(m)	TRIM ANGLE	0.948396	(deg)
CB	0.576706	(-)	CM	0.858803	(-)
AWL	1445.32	(m**2)	CWL	0.782571	(-)
IWL	0.129915E+07	(m**4)	SWL	-6736.08	(m**3)
XWL	-4.66062	(m)			

Mass coefficient

Mass intact ship	0.512192E+07	(kg)
Mass damage fluid	866250.	(kg)

DDH280 Operational Light for downflooding study, October 1999

Static hull coefficients damaged ship

XUT	1156.22	(kg/(m*s))	XUUT	-393.255	(kg/m**2)
XUUUT	6.60446	(kg*s/m**3)	XVRTT	174385.	(kg/m**2)
CUVS	0.289879E-01	(s/m)	CDO	1.45387	(-)
YUVTT	-1946.15	(kg/m**3)	NUVTT	-114579.	(kg/m**2)
YURAOT	86264.1	(kg/m**3)	YURAFT	82106.1	(kg/m**3)
NURTT	-.571675E+07	(kg/m)	CUVTT	0.726200	(-)
KUR	0.686768E+07	(kg*m)			

XBET	70.3821	(m)

Roll damping coefficients damaged ship (according to ROLDAMP - FDS)

KUP	-.154997E+07	(kg*m)	KBPP0	-.128622E+08	(kg*m**2)
KBPP1	0.570344E+08	(kg*m**2*s)	KBPP2	-.948214E+08	(kg*m**2*s2
BEPP	-.142859E+07	(kg*m**2)			

PROGRAM F R E I N P DATE : 22/11/1999 TIME : 11:30:31 PAGE : 10

DDH280 Operational Light for downflooding study, October 1999

Propeller characteristics

Propeller number 1

TNN	:	58.82	(kg*m)
TUN	:	-528.75	(kg)
TUU	:	1606.17	(kg/m)
TU3N	:	-16470.64	(kg/m2)

PROGRAM F R E I N P DATE : 22/11/1999 TIME : 11:30:31 PAGE : 11

DDH280 Operational Light for downflooding study, October 1999

Rudder characteristics

Rudder number 1

Type	:	Rudder	
TPA	:	0.00	(kg/m)
ALFSTO	:	31.64	(deg)
CFNR	:	0.18	(-)
CLY	:	-17803.72	(kg/m)
CNY	:	-10523.88	(kg/m)
CHRU	:	1.19	(-)
CVRU	:	0.63	(-)
ASPEC	:	1.00	(-)

DDH280 Operational Light for downflooding study, October 1999

Parameters for wind computation damaged ship

Asup,y	:	534.60	(m**2)
Asup,x	:	0.00	(m**2)
Ahull,y	:	526.50	(m**2)
Ahull,x	:	0.00	(m**2)
xw0	:	8.68	(m)
zAy	:	-7.39	(m)

B.2 FREDYN Output File Fredyn.out

```
                              F R E D Y N                                      DATE : 18/02/2000
                              ===========                                      TIME : 08:44:40

                              Revision 7.9_0

SIMULATION OF THE BEHAVIOR OF A STEERED SHIP IN WIND AND WAVES WITH (OPTIONAL) DAMAGED COMPARTMENTS
----------------------------------------------------------------------------------------------------------






**** N O T I C E ****

This program has been developed by the Maritime Research Institute Netherlands (MARIN)
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For a detailed description reference is made to:

          * FREDYN 7.7 User's Guide *



Suggestions and comments on the program and documentation are welcome.
Any errors encountered should be brought to our attention.

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```

Summary of input records

Record no.	*	*	*	*	*	*	*	*
0	COMMENT	DDH280 dow	nflooding	study, Ope	rational L	ight		
1	COMMENT	Damage cas	e 05AS mod	elled with	one large	subdivisi	on	
2	COMMENT	Large hole	, no downf	looding				
3	COMMENT	H = 3.25 m						
4	TNKFNM	cpmprm.dat						
5	DATFNM	fridam.dat						
6	OPTION	DAMAOP	PRIWAV	NOLIST				
7	SIMTIME	1000.0	0.0	20.0				
8	INITPOS	0.00	0.000	0.000	0.000	0.0	90.00	90.00
9	INITVEL	0.0	0.0	0.0	0.0	0.0	0.0	
10	RPMPROP	0.0	0.0					
11	SIMPAR		5		150	0.1		
12	DELO	0.000						
13	DELDC	9.000						
14	DELGO	0.0						
15	MAN	1						
16	WAVE1	3.25	9.7	1	0			
17	COMMENT	WIND	0.0	26.5	0	20	1.10	0.6
18	FLOOD1	SUB 100		19.7	0.6	0.0		
19	FLOOD2	-27.432	7.4	6.643	-32.004	7.4	7.01	
20	FLOOD3	-32.004	7.2	4.267	-22.860	7.4	4.267	
21	FLOOD1	SUB 100		19.7	0.6	0.0		
22	FLOOD2	-22.860	7.4	4.267	-32.004	7.2	4.267	
23	FLOOD3	-32.004	4.8	1.524	-27.432	5.5	1.892	
24	FLOOD1	SUB 100		19.7	0.6	0.0		
25	FLOOD2	-32.004	7.4	7.01	-36.576	7.2	6.643	
26	FLOOD3	-41.148	6.4	4.267	-32.004	7.2	4.267	
27	FLOOD1	SUB 100		19.7	0.6	0.0		
28	FLOOD2	-32.004	7.2	4.267	-41.148	6.4	4.267	
29	FLOOD3	-36.576	4.0	1.892	-32.004	4.8	1.524	

```
          Input data read from file :  fridam.dat
          Based on the geometry file:  wspl.dat
          Loading condition :
                KG   intact ship  =          6.393 [m]
                MASS intact ship  =       5121.924 [tonnes]
           Estimated MASS damage fluid =   866.250 [tonnes]
```

```
Summary of compartment contents
-------------------------------
```

Name	Filling [%]	Mass [tonnes]
SUB 100	0.000	0.000
SUB 101	0.000	0.000
SUB 5012	0.000	0.000
SUB 6053	0.000	0.000

```
Total fluid mass in compartments =          0.000 [tonnes]
Fluid mass derived from draught  =        866.250 [tonnes]
```

```
Wave spectrum used in the simulations
-------------------------------------

A Regular Wave were specified as input.
```

Sample rate of output signals 0.100 s

Statistical Analysis of simulation results

notation	units	mean	st.dev.	maximum	minimum	no.samp.
ZETAg1+2	(m)	-0.02	1.15	1.62	-1.62	10000
ALFAy	(deg)	0.00	1.05	3.58	-3.55	10000
Xe	(m)	-125.99	359.00	199.91	-1060.37	10000
Ye	(m)	-24.82	71.16	42.93	-241.50	10000
Ze	(m)	0.51	0.71	2.40	-1.75	10000
PHI	(deg)	14.28	7.45	29.24	-10.10	10000
THETA	(deg)	0.99	1.61	3.50	-1.66	10000
PSI	(deg)	170.42	29.96	197.02	90.00	10000
PSI-PSI0	(deg)	80.42	29.96	107.02	0.00	10000
Ug	(m/s)	1.15	1.49	3.55	-1.15	10000
Vg	(m/s)	-0.13	0.29	1.03	-1.25	10000
Wg	(m/s)	0.06	0.44	1.16	-1.46	10000
P	(deg/s)	0.03	2.49	4.63	-5.98	10000
Q	(deg/s)	0.01	1.08	1.99	-1.78	10000
R	(deg/s)	0.09	0.50	1.70	-1.37	10000
DELTA1	(deg)	0.00	0.00	0.00	0.00	10000

References

[1] "Stability and Buoyancy Requirements - Canadian Armed Forces Surface Ships," Technical Report C-03-001-024/MS-002, Department of National Defence (Canada), August 1991.

[2] J.O. de Kat and H.R. Luth, "FREDYN: A Computer Program for the Simulation of a Steered Ship in Extreme Seas and Wind, Theory Manual, Version 7.0," Technical Report, MARIN, May 1998. Limited Distribution.

[3] J.O. de Kat and A.C.W.J. Oomen, "FREDYN: A Computer Program for the Simulation of a Steered Ship in Extreme Seas and Wind, User's Manual, Version 7.0," Technical Report, MARIN, May 1998. Limited Distribution.

[4] J. Rosborough, "Ship Hull Characteristics Program(SHCP) User's Manual Version 4.12," Report 231072, Naval Sea Systems Command (NAVSEA) 03H32 - Hydrodynamics Division, Washington, May 1994. Limited Distribution.

[5] A.P. van 't Veer and W. Bot, "Fredyn Compartment Description Using GHS," Technical Report 15222, MARIN, March 1999. Limited Distribution.

[6] W.T. Lee and S.L. Bales, "Environmental Data for Design of Marine Vehicles," in *SSC/SNAME Symposium* (Arlington, Virginia, 1984).

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This report examines stability in waves of a damaged Iroquois class ship. Stern asymmetric flooding is the limiting design case for the Iroquois class. To reduce heel angle for this limiting case, DND is considering installing ports to permit downflooding to lower compartments, resulting in a lower centre of gravity for the damaged ship. The computer program FREDYN has been used to examine motions in waves for the damaged ship with and without downflooding. In calm water and moderate sea states, the maximum roll angle occurs during transient motions immediately after damage. These transient motions are not included in current stability criteria. Downflooding significantly reduces the static list of the damaged ship in calm water; however, the initial roll transient that occurs immediately after damage is not significantly influenced by downflooding. For the damaged ship in higher sea states, FREDYN simulations indicate that allowing downflooding gives somewhat reduced roll motions. The FREDYN program appears promising for assessing performance of damaged ships in waves. Further development efforts should be directed toward program validation, robustness, and visualization capabilities.

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